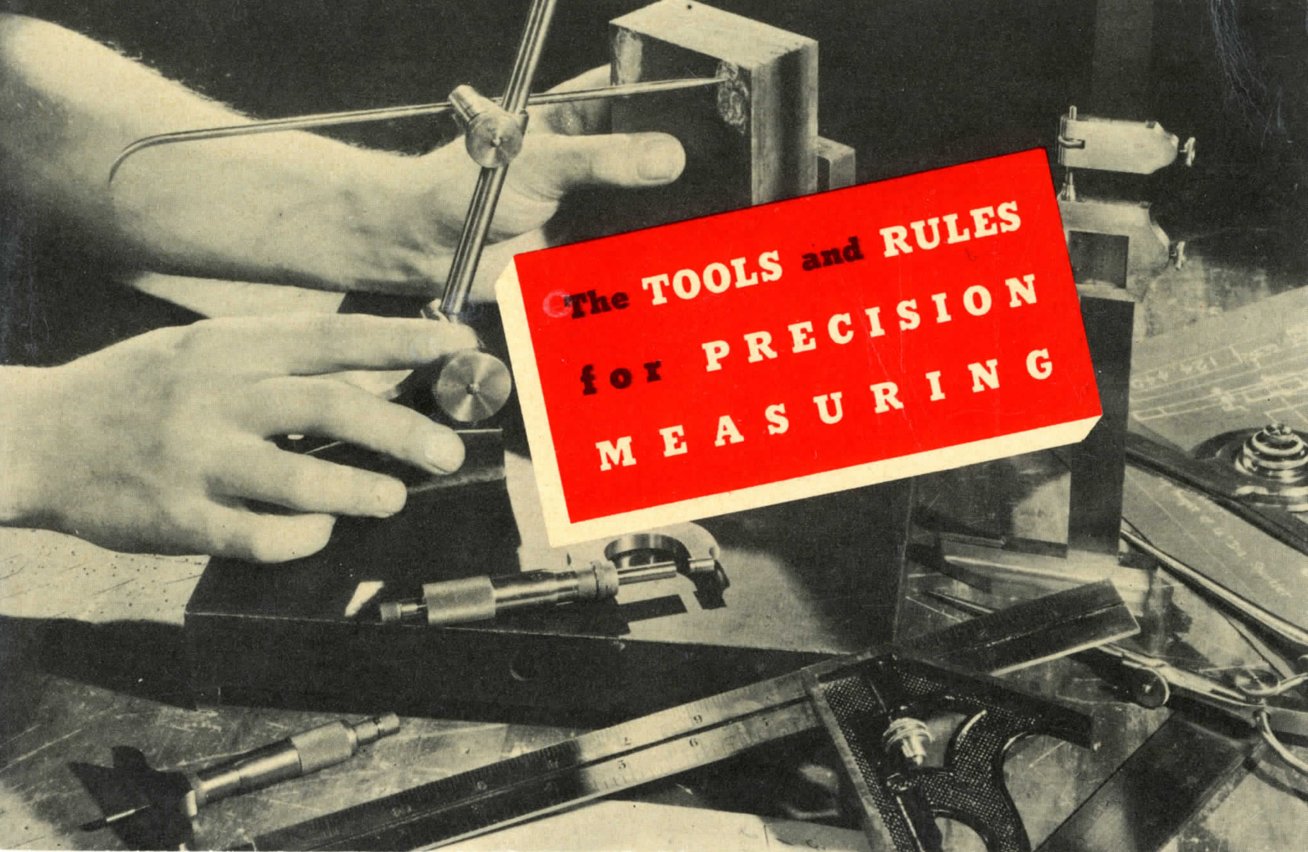
The TOOLS and RULES for PRECISION MEASURING



FOREWORD

This booklet is dedicated primarily to the students in vocational schools and to their counterparts in industry, the apprentices in training classes. We hope it will be of special benefit to those veterans who are training on the job and that it will help to speed the day when they will be fully qualified as skilled craftsmen. We hope, too, that it will, at least in a small way, lighten the burden of those men whose patience, devotion and kindly understanding have taught many a young hand to work accurately and well—the school shop instructors.

This booklet does not pretend to describe or show all of the precision measuring tools available. For that purpose, we can best refer you to the Starrett Catalog which for so many years has been the buying guide and reference book of tool users. Your tool dealer will gladly provide one without charge and, if you have not already done so, we suggest that you take this opportunity to make his acquaintance. You will find him an invaluable source of information, not only about tools, but about the thousand and one other items which he supplies.

THE L. S. STARRETT COMPANY

World's Greatest Toolmakers

ATHOL, MASSACHUSETTS

NEW STANDARDS OF ACCURACY

Scientists have now discovered an atomic "yardstick" which promises to serve as a standard of measurement 10 times more accurate than any heretofore in use. Still in laboratory stages, this new "measuring lamp" contains a special kind of mercury made from gold by atomic bombardment. The light rays which it emits can be used to measure in *billionths of an inch!*

How does this news affect the machinist or precision worker accustomed to thinking in terms of sixty-fourths or thousandths of an inch? The answer is *very little!* Must he change the methods to which he has long been accustomed? Must he learn to use new tools weird and wonderful in form? The answer is *no!*

What it does mean is that science has taken another great stride toward establishing absolute laboratory standards which will permit working within close tolerances with greater ease and accuracy. In industry, it will lead to the development of better, more accurate master gages to be used in the manufacture and inspection of measuring tools. It is in line with the current trend toward greater economy and efficiency through better standards of dimensional control in production and inspection.

Know Your Limits

While on the subject of accuracy, a word of advice may not be amiss. It is quite possible to be too accurate in production work. Striving for accuracy beyond prescribed limits can be just as inefficient and wasteful of time and effort as gross inaccuracy. Not even pride of workmanship can justify one craftsman slowly and painstakingly producing parts to an accuracy of one ten-thousandth while his bench mate turns out matching components that merely meet the specified tolerance of plus or minus several thousandths. What is desired, and that to the highest degree, is the ability to produce work rapidly and consistently that measures up to the established standards. It is the purpose of this booklet to review the means and the methods of achieving uniform accuracy according to the standards commonly accepted in industry today.

THE YARD AND THE METER. Nearly all measurements common in shop practice involve measurements of length. Linear measurements are so numerous and of

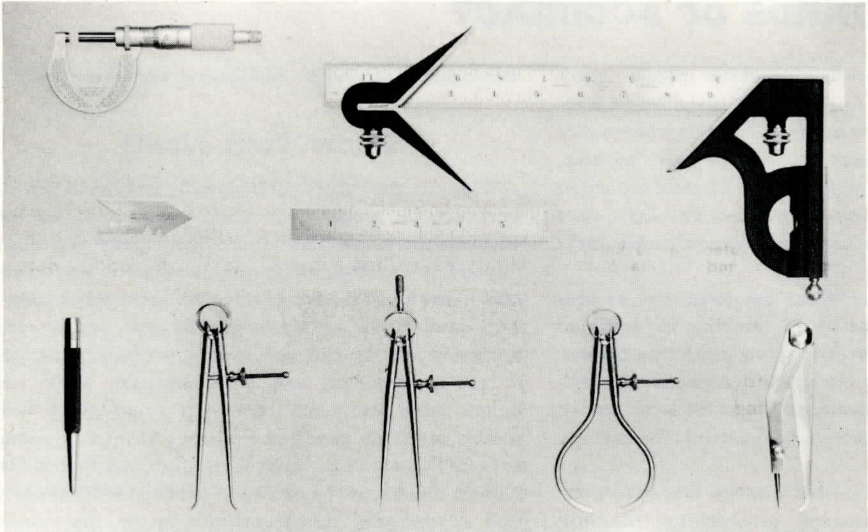


Fig. 1—Most used and most useful. A 1-inch micrometer, Combination Square with center head, Center Gage, 6-inch Flexible Rule, Center Punch, Inside Caliper, Dividers, Outside Caliper and Hermaphrodite Caliper make an excellent nucleus for a set of measuring tools.

such importance that a multitude of measuring tools are available for the purpose of obtaining them.

Two units of linear measurement are now common in the United States. One, the British yard, as defined by the Weights and Measures act of 1878 is most familiar in its subdivisions of feet, inches and fractions of an inch. Once as loosely defined as the distance from the thumb-tip to the end of the nose of English King Henry I, it is now more precisely defined by the British as the distance between lines inscribed on two gold plugs in a bronze bar when taken at a specified room temperature. We, too, have a prototype of the yard which is kept in the Bureau of Standards in Washington but prefer to base our

definition of the yard on the standard for the meter which is even more precisely established in terms of a given number of wave lengths of the red light produced by a cadmium vapor lamp under carefully

Fig. 2—Section of a steel rule graduated by the English System to 64ths inch on one edge and by the Metric System to millimeters on the other.

specified conditions. The meter, which is the basis of the metric system accepted as the standard system of measurement in many countries, is subdivided into centimeters, millimeters, and fractions of a millimeter with one-fiftieth of a millimeter being about the limit encountered in general shop practice. Most shops handling instrument and scientific work as well as producing parts for export are equipped with measuring tools calibrated by the metric system.

Sight and Touch

In striving to develop habits of consistent accuracy in measurement, it is well to remember that we are primarily dependent upon two senses in making nearly all measurements—the sense of *sight* and the sense of *touch*. Not all of us are blessed with perfect vision but any shortcomings in that direction can be largely overcome by corrective eye glasses. A magnifying glass or eye loupe should be part of every precision worker's equipment. Good light, either natural or artificial, is also essential.

The sense of touch becomes important when using contact measuring tools. A skilled mechanic with a highly developed sense of "feel" can readily detect

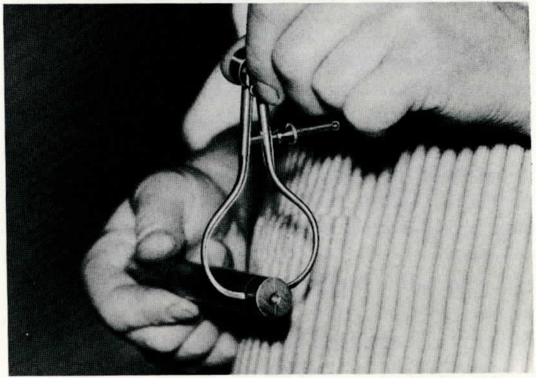


Fig. 3—When contact measuring tools are held lightly by the fingers, it is possible to "feel" extremely slight differences in dimension.

a difference in contact made by changes in dimension as small as 0.00025". While the acuteness of the sense of touch varies with individuals it can be developed with practice and proper handling of tools. In the human hand, the sense of touch is most prominent in the fingertips; therefore, a contact measuring tool should be properly balanced in the hand and held lightly and delicately in such a way as to bring the fingers into play in handling or moving the tool. If the tool is harshly grasped, the sense of touch or "feel" is greatly reduced.

ESTIMATION. Sight and touch are frequently combined by the skilled worker to estimate measurements finer than the graduated limits of a tool. For example, on the average micrometer graduated to read to thousandths of an inch, the space between the smallest graduations on the thimble is approximately 1/16 inch. Variations in size much smaller than the thousandth of an inch which this space represents can readily be felt and judged by eye with reasonable accuracy. It is of course always best practice to work within the limits for which a measuring tool is designed but when circumstances make it necessary, it is possible to extend the limits by estimating sub-divisions of the smallest graduations in simple fractions such a 1/2, 1/3, 1/4, etc.

CARE OF TOOLS. It goes without saying that precision measuring tools should be handled with the greatest of care. Good tools are made of hardened steel and will stand a lifetime of use without breakage but the *accuracy* of even the finest tool can be quickly impaired by careless or abusive treatment. In working with measuring tools, be careful to avoid accidental scratches or nicks that will obscure graduations or distort contact surfaces. Rust is the enemy of all finely finished surfaces. Tools should be wiped clean of finger prints after using and kept

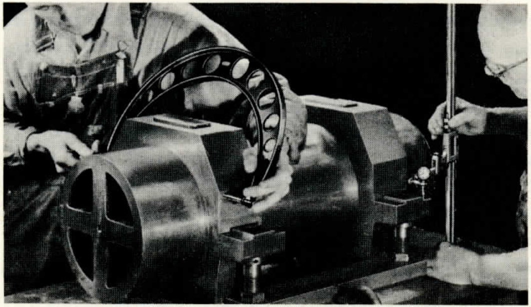


Fig. 4—A variety of tools are used for linear measurements. The man at the left is checking a hard-to-reach dimension with a large Micrometer Caliper. The man at the right is using a Dial Test Indicator mounted on the jaw of a Vernier Caliper to compare the uniformity of height of several similar surfaces.

in separate boxes or cases. A light dressing of oil applied with a soft, lint-free cloth will protect tools in storage.

LINEAR MEASUREMENTS

LINEAR MEASUREMENTS on flat surfaces are perhaps the most common measurements made in general practice. The tool used varies with the size of the dimension, the nature of the work and the degree of accuracy required. It may range from a steel tape, rule, divider or trammel to a micrometer or Vernier caliper. The measurement may be made direct as with a steel rule or slide caliper in which the dimension is read directly from a graduated scale with the tool in contact with the work or it may be made indirectly by comparison with a separate scale or standard using dividers, calipers or a surface gage to transfer the measurement. Many related tools such as straight edges, steel squares and protractors are used in conjunction with linear measuring tools to determine flatness, straightness, squareness and angularity.

FOR ROUND WORK, measurements are usually made by contact, using tools with contact points or surfaces such as spring calipers, micrometers, Vernier calipers, etc. Contact measurements are made in two ways: (a) by pre-setting the tool to the required dimension, using a steel rule, micrometer or other tool as a gauge, and then comparing the set dimension with the actual size of the work and (b) the reverse of this method, viz.: first setting the contact points to the surfaces of the work and then using a steel rule, Vernier or micrometer caliper to read the size. The first method is generally preferred where repeated tests must be made such as in machining a piece to a given size or when checking the same dimension on a number of identical parts. The second method is preferred for determining the actual size of the piece or when an accurate measure of variation from a required standard is desired.

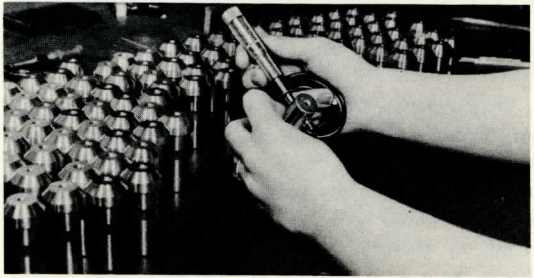


Fig. 5—Inspecting cylindrical work with a Micrometer Caliper. Plus or minus variations from the desired size can be quickly noted and measured.

HOW TO TRANSFER MEASUREMENTS

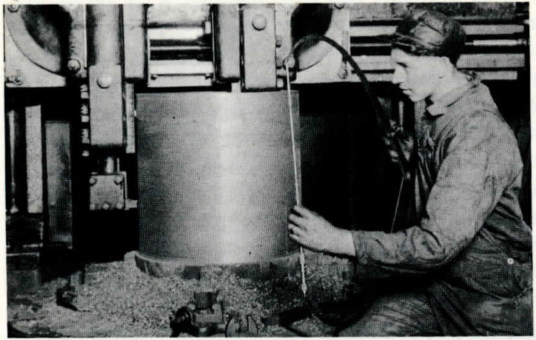


Fig. 6—Pre-setting a large screw-adjusting Firm Joint Caliper to an inside Micrometer Caliper before checking progress of a cylindrical cut.

TRANSFERRING MEASUREMENTS may be a delicate job or not, depending upon the degree of accuracy sought. One of the most common of all tools for transferring measurements is the bow caliper. These are made with the legs curved inward or outward for making outside or inside measurements. When the calipers are set to the work, care should be taken to bring the points into contact without excessive pressure that might cause the legs to spring and introduce an element of error. The measurement is then transferred to a steel rule. In this way, it is possible to transfer lengths with an

Fig. 7—An inside measurement established with a Telescoping Gage is transferred to and measured by a Micrometer Caliper.

error of less than 0.002". More accurate readings can be obtained when a micrometer or Vernier caliper is used to measure the distance between points of the spring caliper. It is here that the sense of "feel" becomes important in judging measurements precisely. Differences in size too small for the eye alone to detect can be readily felt as differences in the ease with which the tool slips over the work or between contacts of the standard. In setting calipers either to the work or to the standard, a firm but not hard contact is desirable. The feel of the slight resistance to movement of the contact points can be retained in the memory long enough for extremely precise comparison between work and standard.

While it is possible in this way to transfer by feel a length with as small an error as one-quarter of one thousandth inch, there are times when it is not practicable to do so without introducing possibilities of error. For that reason, mechanics prefer to use tools which can be read directly in thousandths or ten-thousandths of an inch such as Vernier or micrometer calipers for more accurate contact work. Here again, the sense of feel is important and developing the habit of using the same pressure for every measurement when setting the contact points contributes greatly to uniform accuracy.

STEEL RULES AND RELATED TOOLS

THE RULE is the basic measuring tool from which many other tools have been developed. Rules are so essential and so frequently used on a variety of work that they are offered in a truly amazing selection to suit the needs of the precision worker. They range in size from as small as one-quarter inch in length for measuring in grooves, recesses and keyways to as much as twelve feet in length for large work. Steel rules are graduated in the English or Metric system and sometimes scales for both systems are provided on a single rule. They can be had graduated on each edge of both sides and even on the ends. English system graduations are commonly as fine as one sixty-fourth inch in fractions or one-hundredth inch when graduated decimally. Metric

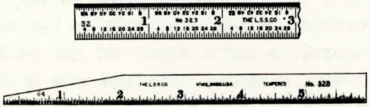


Fig. 8—A thin, flexible, pocket rule with quick reading graduations and a tapered rule for measuring holes and narrow slots.

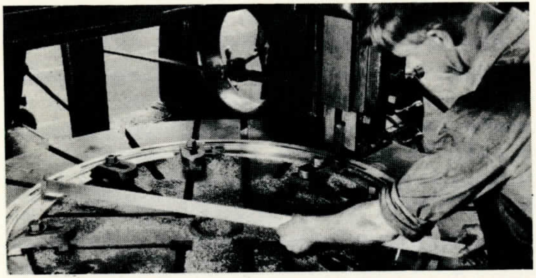


Fig. 9—Note the hook on the end of this long steel rule which insures accuracy when alignment with the work cannot be checked visually.

graduations are usually as fine as one-half millimeter. Starrett rules are graduated to agree with accurate standards furnished by the United States Government. These standards are sent to the Bureau of Standards at Washington at frequent intervals to check for accuracy and so that even minute errors due to wear can be detected and provided for.

VARIATIONS OF THE STEEL RULE. Close working mechanics lean to the 6-inch rule as the most convenient length to carry about on the person. For such purposes, a spring tempered rule is desirable since it is both thin and flexible yet has ample stiffness to provide a straight measuring edge. Small rules may be had with a tapered end for measuring in small holes, narrow slots, from shoulders, etc.

Another favorite pocket rule is the *slide caliper rule* made with a hook on one end and a sliding thumb piece which provide contacts that bear against the work. This rule is especially useful in stockrooms where frequent quick measurements are made on small rods, tubing, sheet stock, etc.

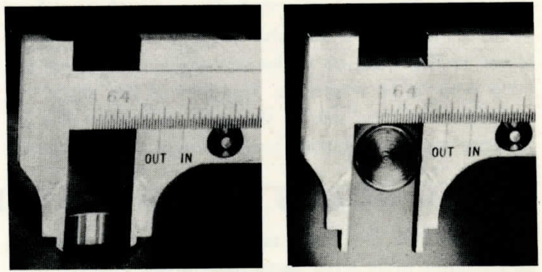


Fig. 10—Pocket Slide Calipers measure both inside and outside dimensions.

The hook feature which is available on many rules is a decided convenience. Not only does it provide an accurate stop at the end of the rule for setting calipers, dividers, etc., but it can be used for taking measurements where it is not possible to be sure that the end of a plain rule is even with the edge of the work.

KEY-SEAT-RULES are necessary for laying off measurements or drawing lines parallel to the axis of cylindrical work such as measuring lengths for splining keyways on shafting. Key-seat rules are angular in cross section with the two edges forming a box square when applied to the surface of a cylindrical piece.

Because long steel rules introduce a storage problem in the tool crib or machinist's kit, they are available jointed to fold to compact size. One Starrett folding steel rule is graduated in the normal way and also in circumference inches so that both the diameter and circumference of cylindrical work can be read directly from the same rule.

SHRINK RULES are used for laying out or working casting patterns and core boxes. Because the contraction of various metals varies greatly as for example: cast iron, 1/8 inch to each foot; brass, 3/16 inch to each foot; and tin, 1/4 inch to the foot, shrink rules are made oversize to allow for this contraction and graduated to distribute the extra length uniformly throughout the rule. Double shrink rules are used when a working pattern is cast from a master pattern as in production moulding and two shrinks must be provided for.

Fig. 11—A Key-Seat Rule is flanged to lie parallel with the axis of cylindrical work.

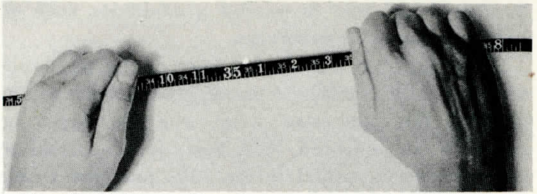


Fig. 12—Quick reading figures on a steel tape eliminate confusion and errors. Foot figures appear beside each inch mark.

THE STEEL TAPE provides a logical extension of a graduated measuring tool beyond the practical limits of a steel rule. Although available in lengths up to 100 feet and more, they are still remarkably accurate. The co-efficient of expansion of Starrett steel tapes as determined by the U. S. Bureau of Standards is 0.000/006/45 per degree Fahrenheit which amounts on a 100-foot tape to only 0.007/74 inch per degree. Starrett tapes are graduated at a standard temperature of 68° Fahrenheit and under a standard over-all tension of 10 pounds.

Like steel rules, steel tapes are available in a choice of graduations including English, Metric,

English-Metric, and in special graduations such as links and poles for surveyors.

Slide Calipers are a refinement of the steel rule which make it possible to insure greater accuracy in aligning the graduated scale with the edges or points to be measured. With these tools, a head or pair of jaws is added to the rule, one jaw being fixed at the end and the other movable along the scale. Provision is usually made for clamping the movable jaw to lock the setting and often a fine pitch screw is provided for fine adjustment of the slide. Readings are made from a line or lines on the slide, a second line usually being provided to allow for the thickness of the jaws when the tool is designed for both inside and outside measurements.

Fig. 13—A Vernier Caliper is a rule developed to its highest form. Direct readings can be made in thousandths of an inch.

Depth Gages are an adaptation of the rule or scale for measuring the depth of holes, recesses, etc. They are provided with a sliding stock or base set at right angles to the scale and with means for clamping the slide to lock the reading.

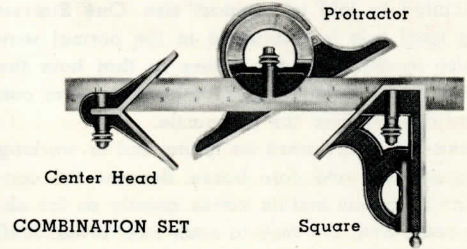


Fig. 14—A Combination Set with its principal parts; a straight edge or rule, a Center Head for locating centers of cylindrical stock, a Protractor Head for laying out angles, and the Square Head which also serves as a mitre, level, etc.

A Combination Square represents a rule developed by means of attachments to the ultimate in utility. It consists of a graduated, hardened steel blade with a sliding try square head that also combines a

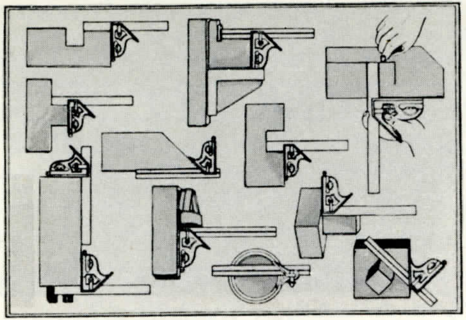


Fig. 15—Some uses of the Combination Square.

mitre and level. This arrangement serves the multiple uses of a rule, square, mitre, depth gage, height gage and level. In addition, an auxiliary centering head can be substituted for the square head for finding the centers of shafting and cylindrical pieces and for measuring the diameter or bore of cylinders.

CALIPERS AND DIVIDERS

As previously mentioned, bow calipers are the most commonly used tool for contact measurement. They are particularly useful for measuring distances between or over surfaces or for comparing dimensions or sizes with standards such as graduated rules. Because they are so frequently used for checking work in a lathe, a word of caution may be in order. Calipers should never be used while the work is turning. At best, the readings are inaccurate and misleading because the friction of the moving surface is sufficient to spring the legs or to draw the contact point away from the true diameter. There is always the danger of having the tool torn out of the hand with possible injury to the user.

CALIPERS with the legs shaped either for inside or outside measurements are made in *spring-bow* style with an adjusting nut and screw working against

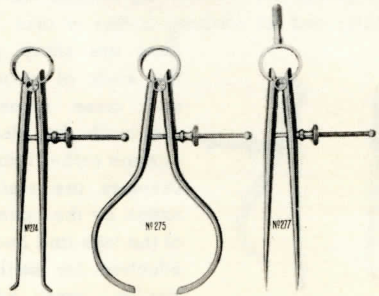


Fig. 16—Inside and outside Calipers and Dividers are typical "contact" measuring tools.

the tension of a spring, in *firm joint* style in which the tension of a nut and stud provides sufficient friction to hold the legs in any set position; and in *lock joint* style with a knurled nut which may be loosened for free movement of the legs and tightened to lock the setting. *Transfer Calipers* are variations of lock joint calipers with a stud or stop on a freely moving leg fitting into a slot or against a stop on an auxiliary leaf. The free leg can be moved in or out to clear collars, flanges or other obstructions and then returned to the original setting against the stop to make the reading.

DIVIDERS are used for measuring dimensions between lines or points; for transferring lengths taken from a steel rule; and for scribing circles or arcs. The contacts are sharp points at the ends of straight legs and close measurements are made by visual comparison rather than by feel. Dividers are restricted in range by the opening span of the legs and become less effective for scribing and similar uses when the points are sharply inclined to the surface worked upon. For transferring or scribing dimensions of considerable length, the mechanic resorts to a *trammel* on which the points are adjustable along a bar or beam and the legs are always perpendicular to the surface worked upon.

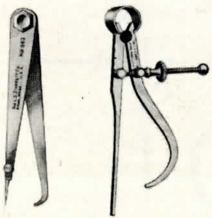


Fig. 17—Hermaphrodite and Keyhole Calipers.

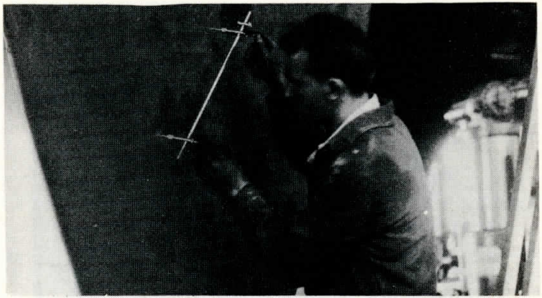


Fig. 18—For scribing or transferring measurements beyond the range of dividers, a Trammel is used.

HERMAPHRODITE CALIPERS combine a straight divider leg and a curved caliper leg and are used for scribing parallel lines from an edge or for locating the center of cylindrical work. *Keyhole Calipers* are similar in appearance to hermaphrodite calipers except that the straight leg does not taper and has a blunt end. They are used for calipering work from a hole or close to an edge where it would be impossible to use a bent leg.

VERNIER TOOLS AND HOW TO READ THEM

The Vernier, invented in 1631 by Pierre Vernier, is in effect a combination of steel rules which permits exceedingly accurate readings. The Vernier Caliper consists of a graduated steel rule or bar on one end of which is a fixed jaw or contact point. A movable jaw sliding on the bar carries a graduated plate arranged so that it may be compared with the fixed scale. The fixed scale is graduated in fortieths of an inch (.025) with every fourth division, representing a tenth of an inch, being numbered. The Vernier plate is graduated so that the space of 25 graduations is equal to 24 divisions on the fixed scale. In other words, each graduated space on the plate is one twenty-fifth of one fortieth of an inch (or one thousandth of an inch) less than a corresponding space on the fixed scale.

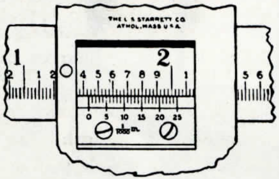


Fig. 19

If the tool is set so that the zeros on the bar and the Vernier scale coincide exactly, it will be noticed that the lines on the bar and scale to the right of the zero marks are out of line, each by an increasing amount, so that the twenty-fifth mark on the Vernier scale is a full division short or, in fact, coincides exactly with the twenty-fourth division on the bar. Remembering that each division on the plate is one thousandth of an inch shorter than each division on

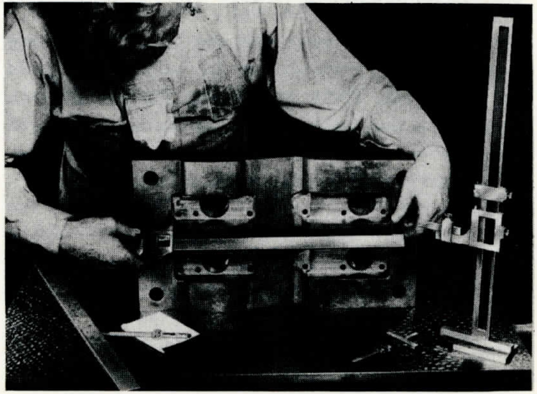


Fig. 20—Using a Vernier Caliper to check dimensions of a drawing die. The mechanic is making a fine adjustment of the jaw by means of the adjusting nut and screw which connects the two slides. Other precision measurements are made with the Vernier Height Gage and the Vernier Depth Gage in the foreground.

the bar, it can be seen that with the zero marks exactly aligned, the first marks to the right on the bar and plate will be .001" out of line, the second marks .002" out, the third .003", and so on. Now, if the slide is adjusted to bring the first two marks into line, the jaws will have opened .001". If the fourth pair of marks are brought into line, the jaws will be open .004", lining up the eighth pair of marks will open the jaw .008", etc.

Once this progression and the reason for it are understood, the principle can be employed to read any part of the scale on the bar. For example, in Figure 19, it can be seen that the Vernier has been moved to the right one and four-tenths and one-fortieth inches plus a slight amount more (1.425+"). It will be noticed also that the eleventh line on the plate is the only line which coincides exactly with a line on the bar. This indicates that the zero mark on the Vernier is eleven thousandths of an inch to the right of the nearest fortieth mark on the bar. Adding eleven thousandths of an inch to the previous reading gives a total reading of one and four hundred and thirty-six thousandths of an inch or 1.436".

The Vernier principle is applied to many tools such as Vernier Height Gages, Vernier Depth Gages, Vernier Protractors, Dovetail Vernier Calipers, Gear Tooth Vernier Calipers, etc. In the case of Vernier Calipers and Vernier Height Gages, scales are frequently provided on opposite sides of the tool for measuring inside and outside dimensions. Care should be taken to use the correct scale since allowance is provided on one side for the thickness of the jaws.

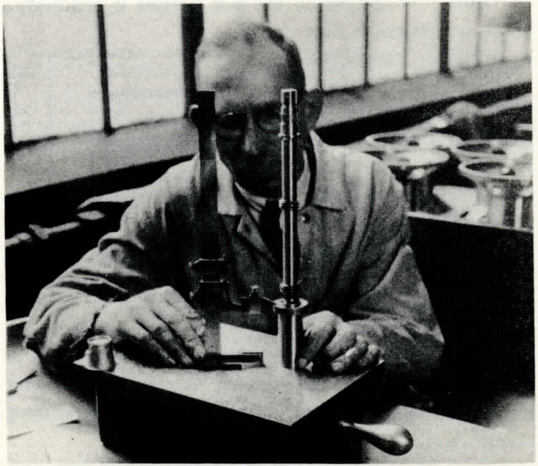


Fig. 21—A Vernier Height Gage is indispensable for measuring or marking off vertical distances when a high degree of accuracy is required.

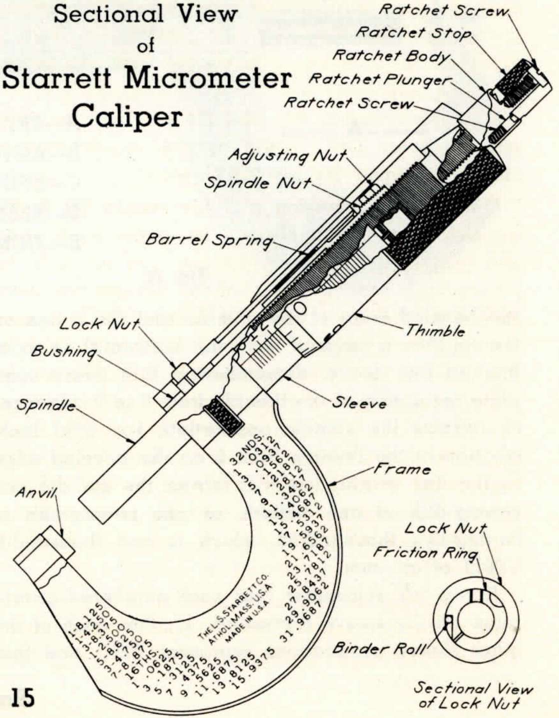
THE MICROMETER AND HOW TO READ IT

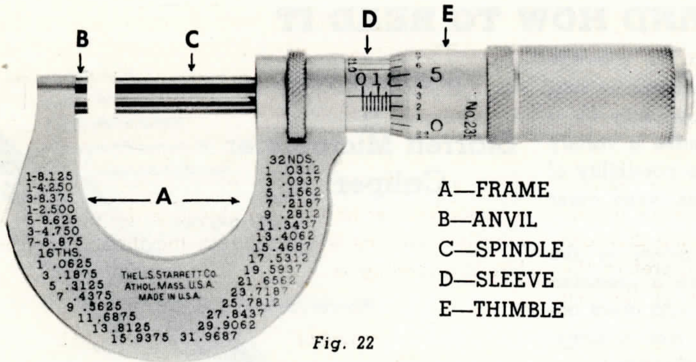
Speak of precision measuring and the average person will think immediately of a micrometer caliper. There is good reason for this popularity for a micrometer caliper can be used to make a variety of accurate measurements without the possibility of error through misreading which exists when other finely graduated tools are used.

In effect, a micrometer caliper combines the double contact of a slide caliper with a precision screw adjustment which may be read with great accuracy. It operates on the principle that a screw accurately made with a pitch of forty threads to the inch will advance one-fortieth (or .025) of an inch with each complete turn. As the sectional view shows, the screw threads are on the spindle concealed by a sleeve. On a micrometer caliper of one inch capacity, the sleeve is marked longitudinally with 40 lines to the inch corresponding with the number of threads on the spindle. Every fourth line is made longer and is numbered 1, 2, 3, 4, etc. to indicate one-tenth inch, two-tenths, etc.

The beveled edge of the thimble is marked into twenty-five divisions around the circumference and numbered from 0 to 25. When the caliper is closed, only the 0 line on the sleeve can be seen next to

Sectional View
of
Starrett Micrometer
Caliper





A—FRAME
B—ANVIL
C—SPINDLE
D—SLEEVE
E—THIMBLE

Fig. 22

the beveled edge of the thimble and the 0 line on the thimble is aligned with the horizontal or axial line on the sleeve. Remembering that every complete revolution of the thimble from 0 to 0 advances or retracts the spindle one-fortieth (or .025) inch, rotation of the thimble from 0 on the beveled edge to the first graduation will retract the spindle one twenty-fifth of one fortieth, or one twenty-fifth of twenty-five thousandths, which is one thousandth (.001) of an inch.

If you will remember that each *numbered* graduation on the sleeve represents .1", that each of the other sleeve graduations represent .025", and that each graduation on the thimble represents .001", you will have no trouble reading a micrometer. For example, in Figure 22, the 1 line is visible which accounts for .100". In addition, there are three more short lines, each representing .025", or combined, .075". On top of that, there are three divisions on the beveled edge of the thimble beyond the 0 mark, each standing for .001" or .003" in all. Adding these up, we have: .100 plus .075 plus .003 equals .178. The reading is .178".

It may help to remember this at first by thinking of the various units as if you were making change. Count the figures on the sleeve as dollars, the unmarked lines on the sleeve as *quarters* and the lines on the thimble as *cents*. Add up your change and put a decimal point instead of a dollar sign in front of the figures.

When the graduations on the sleeve are numbered in the opposite way (from 10 to 0) as on a micrometer depth gage, it should be remembered that the total reading is something *less* than the lowest graduation visible on the sleeve.

How to Read to Ten-Thousandths With a Vernier Micrometer

If you have mastered the principle of the Vernier as explained on page 13, you will have no trouble reading a Vernier Micrometer in ten-thousands of an inch. The only difference is that on a Vernier Micrometer, there are *ten* divisions marked on the sleeve occupying the same space as *nine* divisions on the beveled edge of the thimble. Therefore the difference between the width of one of the ten spaces on the sleeve and one of the nine spaces on the thimble is one-tenth of a division on the thimble. Since the thimble is graduated to read in thousandths, one-tenth of a division would be one ten-thousandth. To make the reading, first read to thousandths as with a regular micrometer, then see which of the horizontal lines on the sleeve coincides with a line on the thimble. Add to the previous reading the number of ten-thousandths indicated by the line on the sleeve which exactly coincides with a line on the spindle. In figure 23B, the 0 on the thimble coincides exactly with the axial line on the sleeve and the Vernier 0 on the sleeve is the one which coincides with a line on the thimble. The reading is therefore an even .2500". In figure 23C, the 0 line on the thimble has gone beyond the axial line on the sleeve, indicating a reading of more than .2500". Checking the Vernier shows that the seventh Vernier line on the sleeve is the one which exactly coincides with a line on the thimble, therefore the reading is .2507".

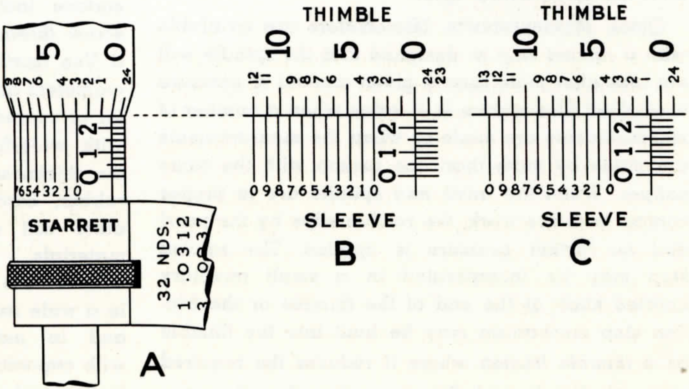


Fig. 23

MICROMETER TYPES AND FEATURES

Adjustment for Wear. Dirt between the anvil and spindle will cause a micrometer to read incorrectly but if these surfaces are clean and brought together carefully and the zero line on the thimble and the axial line on the sleeve fail to coincide it is apparent that some wear has occurred either in the screw or at the contact surfaces. Readjustment is readily made in Starrett Micrometers by turning the friction sleeve by means of a small spanner wrench until the zeros again agree.

Quick Measurements. Micrometers are available with a *ratchet stop* so designed that the spindle will not turn after more than a given amount of pressure is applied. This feature is of value when a number of measurements are made or when the measurements are made by more than one person with the same caliper. When the anvil and spindle are in proper contact with the work, the ratchet slips by the pawl and no further pressure is applied. The *ratchet stop* may be incorporated in a small auxiliary knurled knob at the end of the thimble or the friction stop mechanism may be built into the thimble as a *thimble friction* where it reduces the required span of thumb and fingers and makes it easier to use the micrometer with one hand.

A knurled *lock nut* (see sectional view, Page 15) contracts a split bushing around the spindle, locking the spindle firmly in one position and converting the caliper into a solid gage.

Many shapes and sizes of Micrometer Calipers are available for special purposes such as: *sheet metal micrometers* with deep U frame which permits gaging over beading or flanges or at any point on a surface including near the center of the sheet; *screw thread micrometers* with pointed spindle and a Vee anvil for measuring threads; *ball anvil micrometers* and *tube micrometers* for measuring tubular or curved surfaces; and *paper gage micrometers* with wide-faced anvil and spindle for measuring the thickness of paper, rubber, cardboard and other soft or resilient materials. Micrometer calipers are also made in a wide range of sizes and in *matched sets* with capacities up to 24 inches and more.

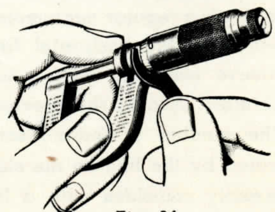


Fig. 24

For service involving continuous hard use or under abrasive conditions, micrometers are available with long wearing *tungsten carbide facings* or *boron carbide inserts* of almost diamond hardness applied to anvils and spindles. Micrometers are also *chromium plated* with Satin Chrome Finish by the manufacturer to make them stain resisting, longer wearing, and to relieve eye strain.

INSIDE MICROMETER CALIPERS are an application of the micrometer screw principle to adjustable end measuring gages. The distance between ends or contacts is changed by rotating the sleeve on the micrometer head up to the extent of screw length, usually either one-half or one inch. Greater distances are obtained by means of extension rods and suitable collars or gages which in various combinations cover the total range of the tool.

Inside micrometer calipers are a little more difficult to use than outside micrometer calipers. With spherical contact points more practice and caution is needed to "feel" the full diametral measurement. Since one contact point is generally held in a fixed position, the other must be rocked in different directions to be sure the tool is spanning the true diameter of a hole or the correct width of a slot.

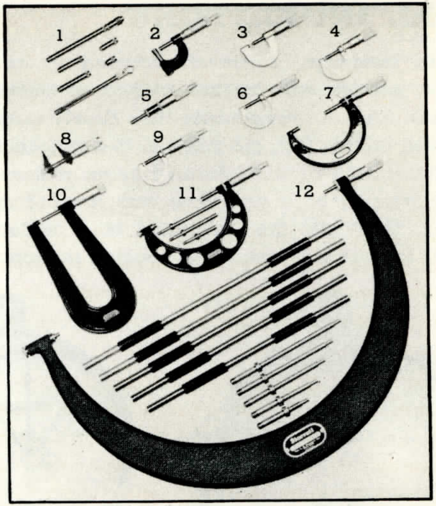
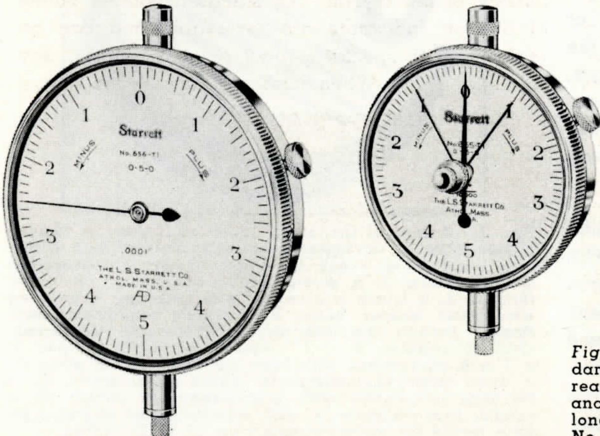


Fig. 25—A few of the many types and sizes of Starrett Micrometers: 1, an inside micrometer caliper with extension rods; 2, a 1-inch tube micrometer for measuring tubular walls; 3, a screw thread micrometer for screw threads; 4, a 1-inch micrometer with lock nut; 5, a 1-inch micrometer caliper head; 6, a 1-inch micrometer with thimble friction and lock nut; 7, a 1½—2½ inch crankshaft micrometer; 8, a 1" inside micrometer caliper; 9, a 1-inch micrometer with lock nut and ratchet stop; 10, a deep throat micrometer for sheet metal work; 11, a 0-4 inch micrometer with interchangeable anvils; 12, a tubular frame micrometer with standards and interchangeable anvils for measurements from 12 to 18 inches.

DIAL INDICATORS

DIAL INDICATORS, commonly referred to as dial gages, provide still another method of measuring to close limits. In appearance they closely resemble a watch and, in fact, are made to fine watchmaking standards with carefully finished gears, pinions and other working parts and often with jeweled movements. The dials are calibrated in a variety of ways; for direct or continuous reading as from 0 to 10, 0 to 50, etc., or for balanced or plus-or-minus readings as 0-5-0, 0-25-0, etc. Because dial indicators are so widely used in the tool and machine industry as part of machine tools, production machines, jigs, fixtures, etc., the National Bureau of Standards, leading dial indicator manufacturers and other interested parties have adopted a series of standards known as the American Gage Design Specifications.



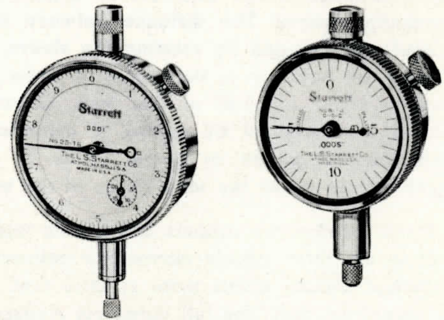


Fig. 26—Typical Starrett Dial Indicators in the four standard American Gage Design sizes: No. 656-T1 (3⅝″ dia.) reading 0-5-0 by .0001″; No. 655-T1 (2¾″ dia.) with tolerance hands, reading 0-5-0 by .0001″; No. 25-T6 (2¼″ dia.) long range indicator with double dial and tell tale hand; No. 81-J (1 11/16″ dia.) reading 0-10-0 by .0005″.

These specifications establish standards for size, range, position of mounting lug, etc.

Essentially, a dial indicator is a rack and pinion mechanism with a suitable gear train for translating a small movement of the rack or spindle into a large movement of the indicating hand. The magnification is controlled by the gear ratio. Normally a fairly short range of spindle travel is adequate and the practice is to have the range equal to two and one-half revolutions of the indicating hand. For special applications requiring greater spindle travel it is possible to obtain *long range indicators* such as a thousandths reading indicator with a range of one inch. Since the hand of an indicator of this type may make as many as ten complete revolutions in covering the range of the instrument, it is provided with a *tell tale* hand or *revolution counter* which is a small auxiliary dial and hand set into the larger dial and which records the number of revolutions of the large hand. For comparative inspection operations, it may be desirable to have the indicator equipped with *tolerance hands* which may be set to indicate the plus and minus limits by means of a small knurled disc mounted on the outside of the crystal. The standard contact points of Starrett Indicators are removable and can be replaced with *special contact points* of almost any shape or length. When service conditions are severe

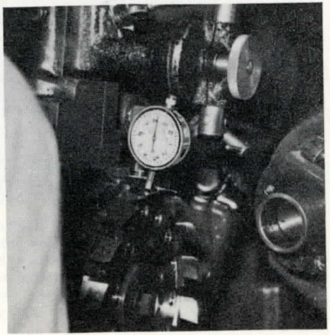


Fig. 27—Checking the setting of teeth in a Hypoid Gear Cutter—one of hundreds of applications in which Dial Indicators are set up on machine tools jigs, fixtures, etc.

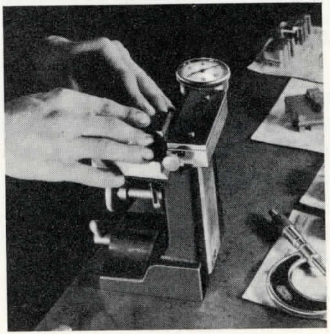


Fig. 28—For production inspection of duplicate parts, it is standard practice to use special fixtures employing one or more Dial Indicators. This one is for gaging thread chasers.

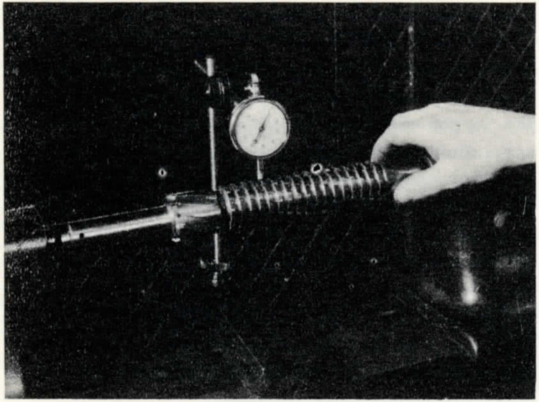


Fig. 29—A general purpose Dial Test Indicator checking the cutting edges of a broach.

and the indicator is subject to harsh use or sharp impact, it is well to specify a *shock resisting* or *shock absorbing type* of indicator. The shock absorbing feature may be embodied in the rack assembly or it may be incorporated as in the patented Starrett Shock Absorbing Anvil Unit in an interchangeable point which may be substituted for the solid type contact point of any A.G.D. Standard indicator.

Dial Test Indicators. Machinists and toolmakers have need of a more versatile and adaptable type of indicator for all-purpose use and find the *Starrett Dial Test Indicator No. 665* or *Starrett LAST WORD* Indicators suited to their requirements. Dial Test Indicator No. 665 is supplied with attachments for using the indicator under almost any conditions such as inspection of jigs and fixtures, on

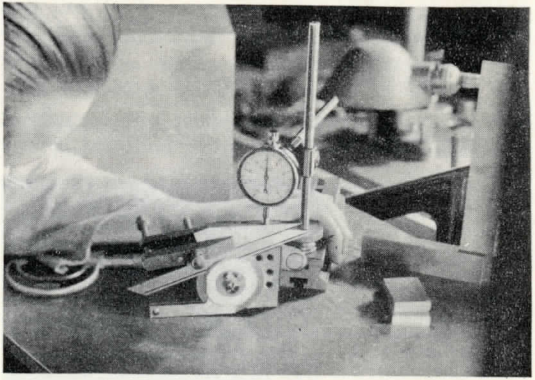


Fig. 30—The ease with which it can be set up for use on a wide variety of work makes this Dial Test Indicator combination particularly valuable to inspectors and toolmakers. As shown here, it is being used to check the accuracy of a small angle parallel. The Steel Square, Bevel Protractor, Toolmakers' Clamp and Micrometer are typical tool room equipment.

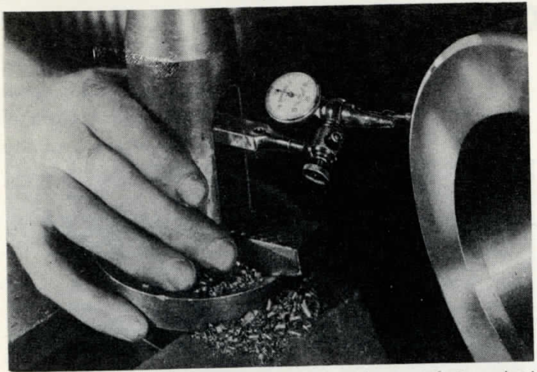


Fig. 31—Starrett LAST WORD Indicator has ratchet contact point, reversible action, swiveling body and universal shank for ready adaptability to any set up or position.

machine ways or platens, on work plates, in keyways, tee slots or beveled surfaces, in tool posts, surface gage spindles, etc. The attachments include base, upright post, horizontal and right angle arm, clamp, tool post holder, swivel, base stops and keyway guide, hole attachment, etc.

LAST WORD INDICATORS are probably the most completely flexible indicators of their type. They are universally adaptable by means of a reversible action ratchet contact point, swiveling tubular body and universal shank so that the tool can be quickly set up and the contact brought to bear on normally inaccessible surfaces such as in holes or slots, over face plate blockings, on either side of a flange, etc., while the dial remains in a convenient position for easy reading. Other popular Starrett Indicators of the Universal Dial Test Indicator type are Nos. 196 and 645. No. 654 which is an inspector's bench gage has the Dial Indicator mounted on a sliding head which is adjustable on a post for height above an adjustable work holding table. Spindle lift and release are by means of a lever which makes the arrangement an excellent gage for inspecting duplicate metal parts as well as samples of rubber, textiles, paper, leather, veneer, mica, plastics, etc.

For detailed description and illustrations of the complete line of Starrett indicators, write for new Starrett Dial Indicator Catalog.

LAYING OUT WITH ACCURACY

LAYING OUT is a shop term which includes the placing of lines, circles, centers, etc., upon the surface of any material to serve as a guide in shaping the finished piece. It is somewhat analogous to mechanical drawing but differs in one important respect. The lines on a mechanical drawing are used only for reference in visualizing dimensions and are not measured or transferred. For that reason, exact accuracy of spacing is not required. In laid out work, even a slight error in placing a line or center may result in a corresponding or greater error in the finished piece. For that reason, all lines should be exactly located and all scriber, divider and center points should be exact and sharp.

Fine and accurate laying out which paves the way for accurate working and finishing continues to be one of the best examples of the precision worker's skill. Far from diminishing in importance as mass production methods introduce wider use of jigs and fixtures for duplicate production of parts, its value grows as the need for greater accuracy in the making of the jigs, fixtures, tools and production machines increases.

PREPARING THE SURFACE. For rough surfaced work such as castings or for simple work where no great accuracy is required, rubbing chalk or a mixture of white lead and turpentine upon the surface of the

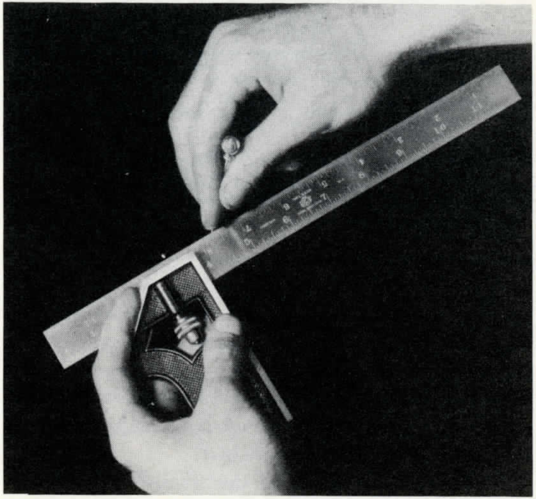


Fig. 32—Scribing lines with a Combination Square. The scriber should be held at a slight angle so that the scribed line will be parallel and as close as possible to the straight edge.

work will serve as a coating to make scribed lines more visible. For fine, exact layouts, on smooth or finished surfaces, a special marking solution should be used. One in common use is a mixture of one ounce copper sulphate to four ounces water to which a little nitric acid may be added. This solution applied to clean iron or steel gives a dull coppered surface on which even the finest scribed lines are clearly visible.

For shops doing a volume of layout work, there is available a commercially prepared product known as *blue layout dope* which may be applied to any metallic surface and which will take clean, sharp scribed lines without chipping or peeling. For best results, the surface should be free of grease, oil, cutting solution, etc., before the dye is applied.

SCRIBING LINES. An important feature of scribers, dividers, scratch gages, tram-

Fig. 33—This self-striking center punch contains a mechanism which automatically strikes a blow when the user exerts downward pressure. Adjustable for a light or heavy indentation, it is especially useful in layout work.

Fig. 34—A large surface plate used as a common, level plane for the work and measuring tools. The work is supported by steel parallels so that the various dimensions of the cylinder can be checked in relation to a flange.

mels, surface gages and similar marking tools is a nicely finished, well tempered point, free from burr or distortion. Points should be checked frequently and ground or honed as required. The straight edges of rules, squares and protractors should also be inspected for dents and nicks and checked for trueness from time to time against a master square. Since the location of centers for drilling and the intersection of lines are marked with punched holes, care in using a center punch is extremely important. Considerable practice is required to develop the knack of striking a single crisp tap or blow with a hammer to produce a deep or shallow dimple as desired. For fine work, an *automatic center punch* in which a built-in, adjustable spring provides the striking force is a great asset since both hands are available to steady the tool and it is not necessary to look away from the exact point of contact until the impression is made.

Laying Out Plate. For accurate laying out and for precision inspection of finished work, some sort of plane surface of reliable accuracy is required as a base for the work and for measuring tools such as surface gages, height gages and steel squares. Special metal plates known as *leveling, surface* or *layout-out plates* are available for this purpose. These are made in various sizes and are finished with a high degree of flatness and smoothness. Care should be exercised in placing and handling work and tools on the plate to avoid scratches and nicks and the plate should be protected with a

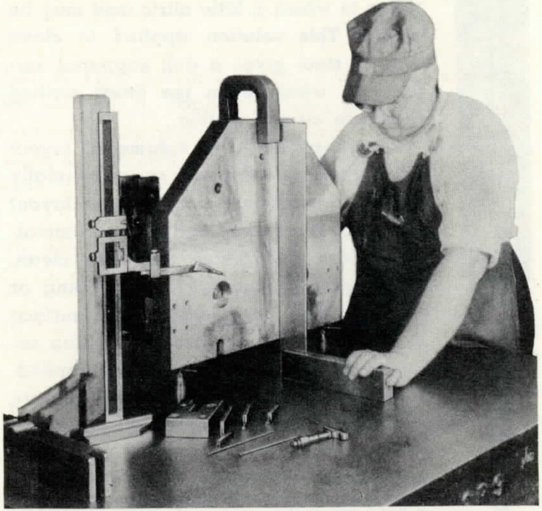


Fig. 35—Lacking a suitable base, the work is supported on small jack screws and clamped square with the plate.

suitable cover when not in use. All burrs, sharp edges and rough areas on the work should be removed before placing it on the plate.

Work of irregular shape or with protruding bosses can be supported and leveled by means of *steel parallels* placed in contact with any two points in a common plane. Parallels are made in matched sets and should be purchased and used in pairs to insure matching accuracy. Finished work or castings with a better bearing surface on the side can be clamped to a *knee* or *angle irons* which are then placed upon or clamped to the surface or face plate. *Toolmakers' Clamps* are used to hold the work securely.

Since much layout work is concerned with the preparation of templates, gages, test and cutting tools, machine parts, jig and fixture parts, etc., it is well to know about the advantages of *Ground Flat Stock.* This is high grade tool steel put up in 18 inch lengths in a variety of widths and thicknesses. It is accurately ground to within .001 inch in thickness and annealed for easy machining. Many shops have no facilities for grinding to close limits and even those which do, prefer the time-saving advantage of keeping a stock of frequently needed widths and thicknesses on hand. Starrett Ground Flat Stock is available in two types: *water hardening* which develops maximum hardness when cooled rapidly in water, and *oil hardening* which is non-deforming and shows little if any change in volume from the annealed state after quenching in oil.

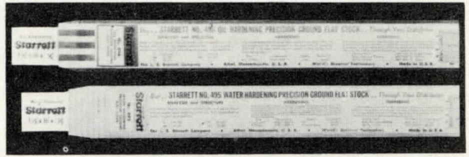


Fig. 36—Each piece packed in protective envelope with dimensions and heat treating instruction clearly shown.

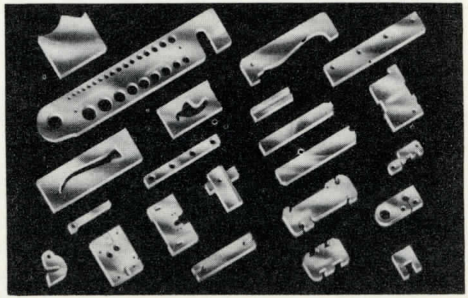


Fig. 37—Some of the tools, gages, parts and pieces readily made with Starrett Precision Ground Flat Stock.

MEASURING LATHE WORK

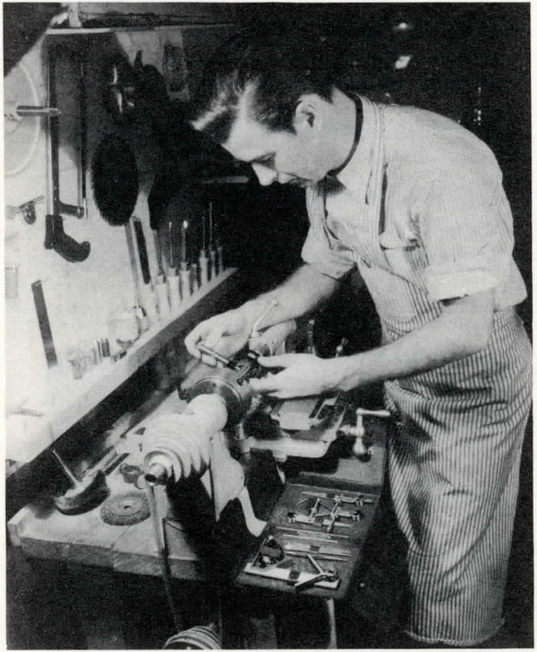


Fig. 38—A kit of essential Starrett measuring tools suitable for school or home workshop and for general lathe work.

Work done in the engine lathe is of such variety that a considerable list of measuring tools may be needed to cover all cases. Ordinarily, however, the principal measurements are concerned with centering the work in the lathe, measuring length and measuring diameters.

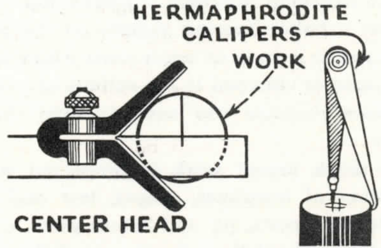


Fig. 39—Two methods of locating centers.

CENTERING THE WORK. For efficient turning with a minimum of waste, and without excessive vibration, it is necessary to locate the center of work to be turned with considerable accuracy. When the work is turned from ordinary cylindrical bar stock, this can be done readily using the center head attachment and the blade of a combination square

Fig. 40 — A Starrett Center Gage used for checking lathe centers and for setting thread cutting tools.

to scribe center lines on the end of the piece, shifting the tool about 90 degrees between lines to arrive at a common center. A hermaphrodite caliper may also be used with the legs opened to approximately half the diameter of the piece. Three or four arcs scribed from various points on the circumference will narrow down the location so that the true center can be estimated with considerable accuracy. The centers as determined by either method just described should be set with a center punch and then tested by spinning the piece in a lathe to check concentricity before drilling and countersinking the center holes. Where there is reason to suspect some distortion or variation in diameter of the work such as in forgings, it is good practice to use a height or surface gage and a surface plate to determine the centers. Lines scribed on the ends with reference to various points on the circumference will locate the center with provision for a fair average of surface errors and insure a reasonable balance while turning the forging to uniform diameter. Work so distorted as to teeter on the surface plate should be placed upon parallels or straight edges.

Center holes are countersunk to match the 60° included angle of lathe centers. It is good practice to check the angle of the live and dead center points from time to time to make sure that they

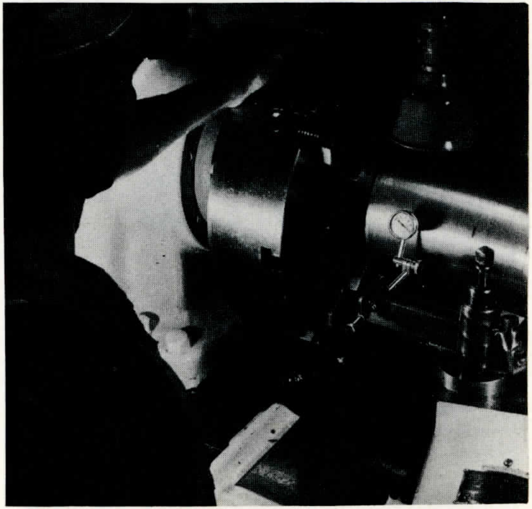


Fig. 41—Checking work for concentricity with a Dial Test Indicator. Note that the work is revolved by hand.

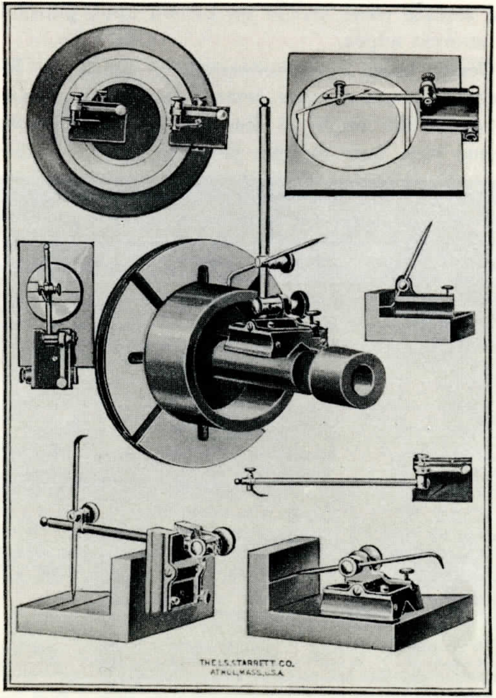
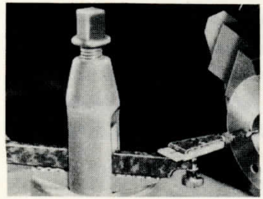


Fig. 42—A Starrett Surface Gage and some of its uses.

have not become worn or distorted. This is done with a *center gage*, a little tool that is also useful in grinding and setting thread cutting tools.

Measurements of Length and Diameter are performed with steel rules, calipers and dividers, micrometers, Vernier calipers, etc., according to the nature of the work and the degree of exactness required. In addition to these, the lathe operator finds considerable use for a surface gage, test indicators, telescoping gages and inside micrometers. The *surface gage* is useful for scribing lines around



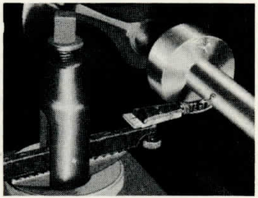
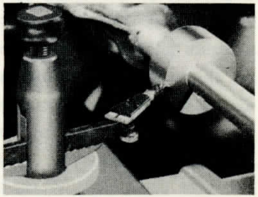


Fig. 43 — A Starrett "Universal Jr." Indicator and some of its many applications to lathe work.



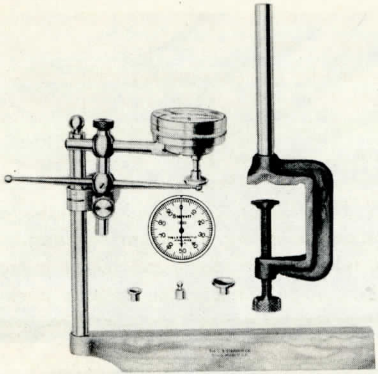


Fig. 44—A Starrett Universal Dial Test Indicator with attachments.

cylindrical work or for scribing concentric circles on the face of work held in a chuck. *Test indicators* vary from a simple needle and sector arm arrangement to highly accurate and sensitive dial test indicators. These are especially valuable for truing up work in a lathe chuck since they can be used for checking internal and external concentricity as well as surface alignment.

TELESCOPING GAGES are sometimes preferred to ordinary leg calipers for measuring internal diameters. The head of a telescoping gage expands across the hole and may be locked and calipered with a micrometer (see Fig. 7) to determine the exact size or the gage may be set to a standard and used to make shrink, close or loose fits.

SMALL HOLE GAGES serve the same purpose for holes ranging from 1/8 to 1/2 inch. They are made with a split ball at the contact end which is expanded to get the measurement which is then transferred to a micrometer.

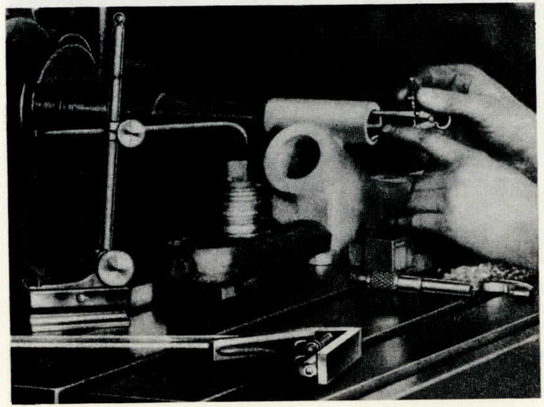


Fig. 45—Checking the diameter of a hole after boring. The Micrometer is used to read the size of the caliper setting.

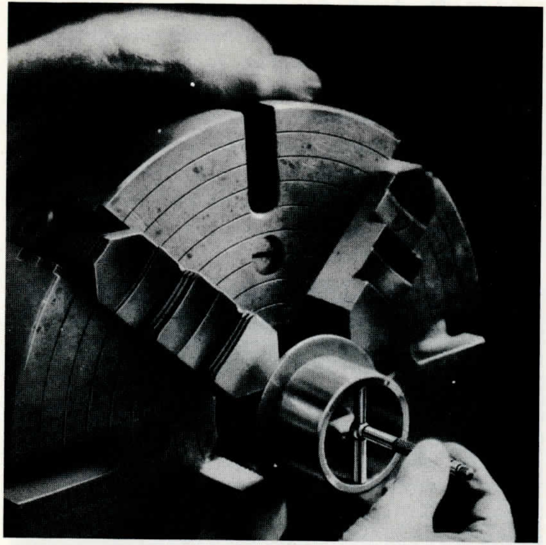


Fig. 47

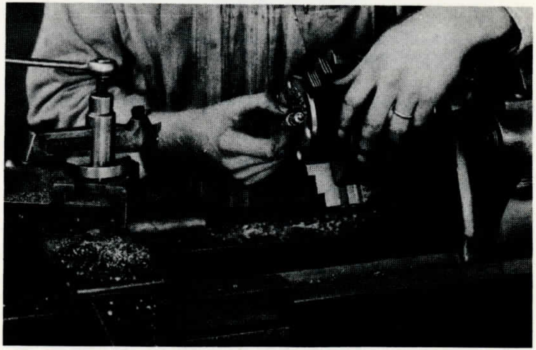


Fig. 48

Fig. 46—By setting a telescoping Gage to a caliper or micrometer, holes can be made and measured for shrink, close or loose fits.

Fig. 47—Small hole gages are used for measuring holes too small for telescoping gages. This set of four covers a range from 1/8 to 1/2 inch.

Fig. 48—Checking the inside diameter of a collar with an Inside Micrometer.

MEASURING SCREW THREADS

Quantity measurements of screw threads are best performed with special thread gages or comparators but there are frequent occasions when such equipment is not available or when it is necessary to determine the number of teeth per inch, the pitch or the pitch diameter of a few bolts, nuts or threaded holes or studs. Where a count of threads per inch is desired, an ordinary steel rule may be used. Count the number of threads between inch graduations with the end of the rule exactly aligned with the root of one thread. Often the result will be less than a whole number or a whole number of threads plus a fraction of a thread. To arrive at the exact fraction, count the number of threads between the end of the rule and the first inch graduation that coincides exactly with a thread. Divide the number of threads by the number of inches.

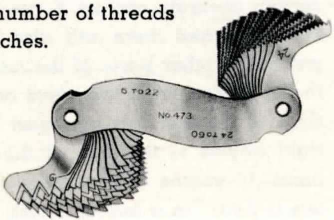


Fig. 49—A Screw Pitch Gage. This gage has a positive stop which holds the leaves in a fixed and convenient position for use.

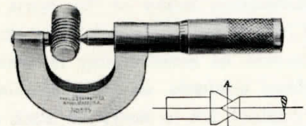


Fig. 50—A Screw Thread Micrometer. With the spindle closed as in the small sketch, the 0 on the thimble represents a reading taken at line AB.

Screw pitch can be determined readily with a *screw pitch gage* which is a set of thin leaves on the edge of which are teeth corresponding to standard thread sections. The leaves of Starrett Screw Pitch Gages are stamped to show the pitch number of the thread and also the double depth of the thread in decimals. This information is helpful in selecting the right diameter drill to use before tapping holes. Because the outside and inside or major and minor diameters of threaded pieces may vary depending upon the sharpness or fullness of the thread, measurements are usually made at the *pitch line* to find the *pitch diameter*. The pitch diameter is equivalent to the theoretical full diameter less the depth of one thread. *Screw thread micrometers* with a pointed spindle and V-shaped anvil are used to measure pitch diameters. The point of the spindle and the vee shaped anvil are designed so that contact is made on the side of the thread.

FACTS ABOUT FITS

In machine construction many of the parts bear such a close and important relation to one another that a certain amount of hand fitting is essential to make the surface contacts as they should be. If the surfaces in contact are to move on each other the fit is classed as a sliding or running fit. If the surfaces are to make contact with sufficient firmness to hold them together under ordinary use, the fit is classed either as a driving, shrink, or forced fit.

SLIDING FITS. Under this head may be classed the fitting of cross and traversing slides of lathes, milling machines, drilling machines, boring machines, grinding machines, and planers. These fits are usually obtained by scraping. In most of these fits the moving and stationary parts are held in contact with each other by means of adjustable contact strips or gibs. In some cases, such as the tables of grinding and of planing machines, their weight keeps them in sufficiently close contact.

RUNNING FITS. The journal bearings of spindles, crank shafts, line shafting, etc., are classed under this heading.

FORCED FITS AND SHRINK FITS. Under this head are classed those fits where the separate parts must act in use as if they were a single piece; as, for example, the crank pins and axles in locomotive driving wheels or the cutter heads and spindles of numerous woodworking machines. A *forced fit* is obtained by pressing one piece into another. A *shrink fit* is obtained by heating the outside piece, bringing it into proper relationship with the inside piece and allowing it to shrink into position as it cools.

LIMITS. In the case of running and of sliding bearings a certain amount of hand fitting is necessary to obtain desired results, and in all cases certain limiting requirements prevail. In sliding and running bearings the limits are usually those of alignment and of contact, while in either journal bearings or in flat sliding bearings it is essential that certain accurate contact between the surfaces shall be made, and there will also be a limit of alignment with other parts of the machine. For example, in the engine lathe the ways or vees and the cross slide of the tool carriage must be parallel to or at right angles to the axis of the spindles within set limits. In engine lathe construction the limit set for this is 0.001" in a foot of length. In testing the parts,

use is made of the Universal Test Indicator with the needle reading on a dial or upon a sector arm. The indicator may be clamped to a test bar, a straight edge, or direct to the lathe spindle; also, if desired, it can be and often is held upon a special slider stand fitted to the vees of the machine.

In the making of shrinkage and forced fits the limits are usually those of size. The amount of pressure necessary to place the two parts together is the limiting factor in the case of forced fits. In forcing the axles into locomotive driving wheels, the specifications may limit the pressure to between one hundred to one hundred and fifty tons. However specified, it in fact reduces to limits of size and the use of measuring tools.

Amounts to Leave. Where pins, spindles, etc., are to be forced into holes, or where collars, hubs, flanges, and other machine parts are to be shrunk on to spindles, it is customary to make the diameter allowance upon the spindle rather than upon the hole. The amount which it is necessary to add to the spindle or shaft diameter must of necessity vary with the length and diameter of the hole, the metals used, and the form of the surrounding hub. The tables on the following page show the tolerances used by one manufacturer.

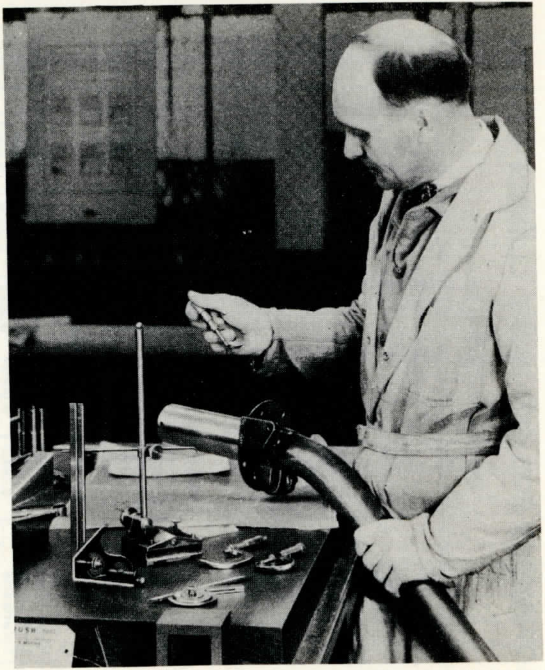


Fig. 51—Inspection operations are greatly simplified and expedited by the right kind of precision tools. This man is checking part of an aircraft landing gear.

ALLOWANCES FOR DIFFERENT CLASSES OF FITS

(Newall Engineering Co.)

Class	Nominal Diameters	Up to ½″	$\frac{9}{16}$″–1″	$1\frac{1}{16}$″–2″	$2\frac{1}{16}$″–3″	$3\frac{1}{16}$″–4″	$4\frac{1}{16}$″–5″
	Tolerances in Standard Holes*						
A	High Limit	+0.0002	+0.0005	+0.0007	+0.0010	+0.0010	+0.0010
	Low Limit	—0.0002	—0.0002	—0.0002	—0.0005	—0.0005	—0.0005
	Tolerance	0.0004	0.0007	0.0009	0.0015	0.0015	0.0015
B	High Limit	+0.0005	+0.0007	+0.0010	+0.0012	+0.0015	+0.0017
	Low Limit	—0.0005	—0.0005	—0.0005	—0.0007	—0.0007	—0.0007
	Tolerance	0.0010	0.0012	0.0015	0.0019	0.0022	0.0024
	Allowances for Forced Fits						
F	High Limit	+0.0010	+0.0020	+0.0040	+0.0060	+0.0080	+0.0100
	Low Limit	+0.0005	+0.0015	+0.0030	+0.0045	+0.0060	+0.0080
	Tolerance	0.0005	0.0005	0.0010	0.0015	0.0020	0.0020
	Allowances for Driving Fits						
D	High Limit	+0.0005	+0.0010	+0.0015	+0.0025	+0.0030	+0.0035
	Low Limit	+0.0002	+0.0007	+0.0010	+0.0015	+0.0020	+0.0025
	Tolerance	0.0003	0.0003	0.0005	0.0010	0.0010	0.0010
	Allowances for Push Fits						
P	High Limit	—0.0002	—0.0002	—0.0002	—0.0005	—0.0005	—0.0005
	Low Limit	—0.0007	—0.0007	—0.0007	—0.0010	—0.0010	—0.0010
	Tolerance	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
	Allowances for Running Fits†						
X	High Limit	—0.0010	—0.0012	—0.0017	—0.0020	—0.0025	—0.0030
	Low Limit	—0.0020	—0.0027	—0.0035	—0.0042	—0.0050	—0.0057
	Tolerance	0.0010	0.0015	0.0018	0.0022	0.0025	0.0027
Y	High Limit	—0.0007	—0.0010	—0.0012	—0.0015	—0.0020	—0.0022
	Low Limit	—0.0012	—0.0020	—0.0025	—0.0030	—0.0035	—0.0040
	Tolerance	0.0005	0.0010	0.0013	0.0015	0.0015	0.0018
Z	High Limit	—0.0005	—0.0007	—0.0007	—0.0010	—0.0010	—0.0012
	Low Limit	—0.0007	—0.0012	—0.0015	—0.0020	—0.0022	—0.0025
	Tolerance	0.0002	0.0005	0.0008	0.0010	0.0012	0.0013

* Tolerance is provided for holes, which ordinary standard reamers can produce, in two grades, Classes A and B, the selection of which is a question for the user's decision and dependent upon the quality of the work required; some prefer to use Class A as working limits and Class B as inspection limits.

† Running fits, which are the most commonly reuqired, are divided into three grades: Class X for engine and other work where easy fits are wanted; Class Y for high speeds and good average machine work; Class Z for fine tool work.

LIMITS OF TOLERANCE

While it is possible to produce machine parts with measurements refined to any degree of accuracy, extreme precision may prove too costly for commercial work.

To avoid waste of time, labor, and money, the following may be considered a representative set of rules to be used when experience and familiarity with the work do not indicate the exact limits to use. They define the degree of accuracy to be expected in those cases where specifications and drawings do not call for greater precision than the rules provide for.

(1) Full information regarding limits of tolerance should be clearly shown by drawings submitted, or be definitely covered by written specifications to which reference must be made by notations on the drawings.

(2) Where the customer fails to supply proper data as to limits, the supplier will use his best judgment in deciding just what limits it may be advisable to work to. The supplier will not, in any event, assume responsibility for possible excessive cost brought about through working to closer limits than may be necessary nor for permitting greater latitude than may subsequently be found to be proper.

(3) Where dimensions are stated in common fractions (1/2, 1/4, 1/8, etc.) with no limits of tolerance specified, it will be assumed that a considerable margin for variations from figured dimensions is available; unless otherwise ordered, the supplier will proceed according to the dictates of his best judgment as to what limits should be taken.

(4) For all important dimensions *Decimal* figures should be used and limits clearly stated on detail drawings. If *Decimal* figures are not used for such dimensions a notation referring to the degree of accuracy required must be placed prominently on the drawing.

(5) It is frequently necessary to reduce fractions representing fourths, eighths, sixteenths, thirty-seconds, and sixty-fourths to decimal equivalents. When a dimension of this character is expressed in a decimal equivalent and carried out to three, four, or five places and limits are not specified it will be assumed that a limit of plus or minus .001 is permissible unless otherwise ordered.

(6) Where dimensions are stated in decimal figures derived by other processes than those explained in paragraph five, but with limits not speci-

fied, the amount of variation from dimensions stated depends upon the customary practice among individual industries and manufacturers. There are no universally accepted tolerance standards. The following were used in one particular instance and cannot be considered as anything more than representative:

Two place decimals	.005 plus or minus
Three place decimals	.0015 plus or minus
Four place decimals	.0005 plus or minus
Five place decimals	.0002 plus or minus

(7) Where close dimensions, such as the location of holes from center to center in jigs, fixtures, machine parts, and other exact work of like character are required, detail drawings should be prominently marked "ACCURATE" and plus or minus limits clearly indicated.

(8) The dimensions of internal cylindrical gages, external ring gages, snap gages, and similar work specified to be hardened, ground, and lapped, will be obtained as accurately as the best mechanical practice applying to commercial work of the particular grade specified will permit.

(9) As drilled holes vary in size from .002" to .015" (and in some cases even more) over the size of the drill used, those holes which require to be made accurately to definitely specified sizes should be either reamed, ground or lapped after boring, and detail drawings thereof should bear notations accordingly.

(10) National Standard form of thread and pitches will be used for ¼-inch and all sizes above. A.S.M.E. Standard will be used for numbered sizes below ¼-inch.

MISCELLANEOUS TOOLS

PROTRACTORS. Measuring the angular relationship of two or more lines or, as it is termed, "reading the angles," can be performed with a variety of tools depending upon the degree of exactness and the job in hand. For simple angles, a common *protractor* will serve, this being either semi-circular or rectangular in shape but with a half circle (180°) graduated in degrees so that angles can be measured or laid out. The rectangular shape has the advantage that any one of four edges can be used as a vertical or horizontal line of reference.

BEVELS. For comparing or checking angles, a *bevel* serves the same purpose as a steel square for rectangles. It consists of a stock and pivoted blade joined by a locking screw. The bevel can be set to

a protractor and used as a gage when turning angles on a lathe or the stock and blade can be locked to transfer any angle from the work to a protractor. The addition of an auxiliary blade results in a *combination bevel,* a more versatile and adaptable tool.

BEVEL PROTRACTORS. A protractor and bevel are combined for greater convenience in the *universal bevel protractor.* It consists of a graduated disk with a fixed blade and an adjustable stock. With this tool, any angle may be laid off or measured by reading the angle of stock and blade as shown on the protractor scale in degrees. The addition of a Vernier plate increases the accuracy of direct readings to a limit of five minutes or one-twelfth of one degree.

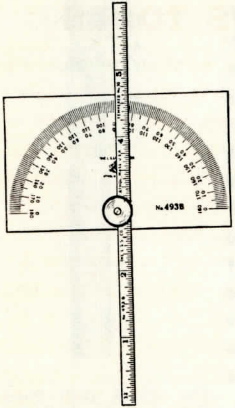


Fig. 52—Starrett No. 493B Protractor may also be used as a depth gage.

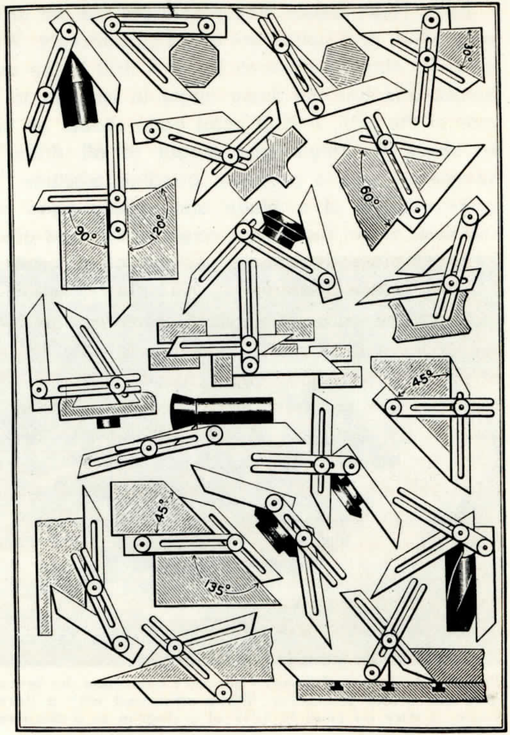


Fig. 53—Applications of the Combination Bevel.

DRILL POINT GAGES. Accurate holes can be drilled only when drill points are ground accurately. When properly sharpened, each lip of a drill is the same length and has the same angle in relation to the axis of the drill. A drill point gage should be used to check lip angle and length of all drills not sharpened with a precision grinding machine. The gage consists of a blade and sliding head with the head set at the correct angle of 59° and graduated to compare lip lengths to within 1/64 inch.

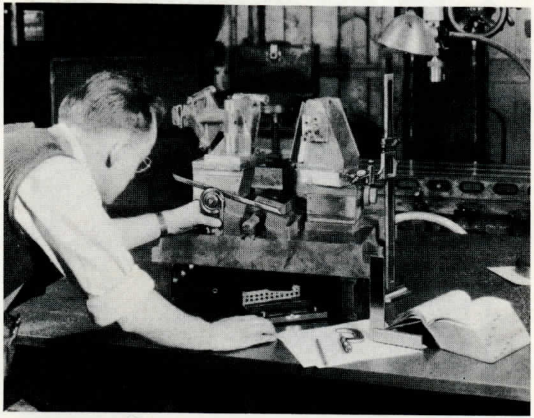


Fig. 54—A Universal Bevel Protractor combines the features of a bevel and protractor. When equipped with a Vernier scale, it may be read to 1/12 of a degree or 5 minutes.

Checking the clearance angle of milling cutters and reamers which may vary from 2 degrees to 15 degrees according to the design is made easy with a *Cutter Clearance Gage*. Consisting of a frame with a protractor section graduated in degrees, an adjustable bar and a pivoted blade, the tool may be used to check either side or peripheral clearances of end, side, spiral, helix or inserted tooth cutters from 2 to 30 inches in diameter. Readings are made direct and it is not necessary to remove the cutter from the arbor of the milling machine or grinder to check clearance as with other less effective methods.

A UNIVERSAL PRECISION GAGE is used to set the cutting tool

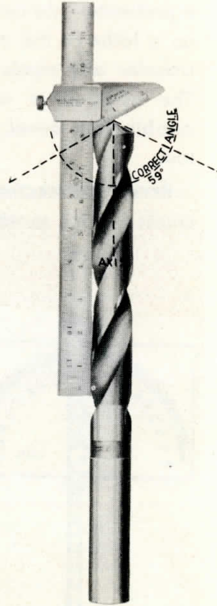


Fig. 55—A Drill Point Gage checks both lip angle and lip length, insuring properly sharpened drills.

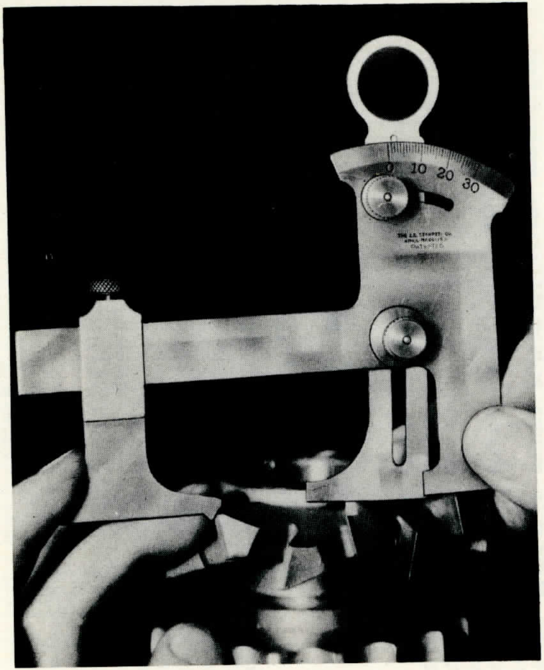


Fig. 56—The Cutter Clearance Gage is adjustable for measuring the clearance angle of any type of cutter.

of a planer or shaper as shown in Fig. 57. This gage with its range of $10\frac{1}{4}$ inches, fine adjustment, inbuilt level, and scriber and offset attachments can also be used as a surface or height gage, for settings in narrow areas, for gap measurements, face to face, as an adjustable parallel, for transferring settings with indicators, for checking and layout, as a scriber, with gage blocks, etc.

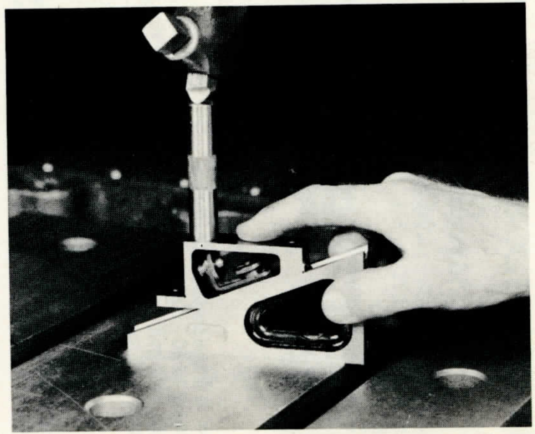


Fig. 57—By setting a Universal Precision Gage to a micrometer, height gage or vernier caliper and then bringing the cutting tool of a planer or shaper into contact with it, the first cut may be absolutely relied upon.

MISCELLANEOUS MEASUREMENTS

Measures of Length

1 mile = 1760 yards = 5280 feet.
1 yard = 3 feet = 36 inches.
1 foot = 12 inches.

The following measures of length are also used occasionally:
1 mil = 0.001 inch. 1 fathom = 2 yards = 6 feet.
1 rod = 5.5 yards = 16.5 feet. 1 hand = 4 inches.
1 span = 9 inches.

Surveyor's Measure

1 mile = 8 furlongs = 80 chains.
1 furlong = 10 chains = 220 yards.
1 chain = 4 rods = 22 yards = 66 feet = 100 links.
1 link = 7.92 inches.

Square Measure

1 square mile = 640 acres = 6400 square chains.

1 acre = 10 square chains = 4840 square yards = 43,560 square feet.

1 square chain = 16 square rods = 484 square yards = 4356 square feet.

1 square rod = 30.25 square yards = 272.25 square feet = 625 square links.

1 square yard = 9 square feet.
1 square foot = 144 square inches.
An acre is equal to a square, the side of which is 208.7 feet.

THE METRIC SYSTEM

Measures of Length

1 Millimeter (mm.) = ...0.03937079 inch, or about 1/25 inch
10 Millimeters = 1 Centimeter (cm.) = ...0.3937079 inch
10 Centimeters = 1 Decimeter (dm.) = ...3.937079 inch
10 Decimeters = 1 Meter (m.) = 39.37079 inches, 3.2808992 feet, or 1.09361 yards
10 Meters = 1 Decameter (Dm.) = ...32.808992 feet
10 Decameters = 1 Hectometer (Hm.) = ...19.927817 rods
10 Hectometers = 1 Kilometer (Km.) = 1093.61 yards, or 0.6213824 mile
10 Kilometers = 1 Myriameter (Mm.) = ...6.213824 miles
1 inch = 2.54 cm., 1 foot = 0.3048 m., 1 yard = 0.9144 m., 1 rod = 0.5029 Dm., 1 mile = 1.6093 Km.

DECIMAL EQUIVALENTS, SQUARES, CUBES, SQUARE AND CUBE ROOTS, CIRCUMFERENCES AND AREAS OF CIRCLES, FROM 1/64 TO 1/2 INCH

Fraction	Dec. Equiv.	Square	Sq. Root	Cube	Cube Root	Circle*	
						Circum.	Area
1/64	.015625	.0002441	.125	.000003815	.25	.04909	.000192
1/32	.03125	.0009766	.176777	.000030518	.31498	.09817	.000767
3/64	.046875	.0021973	.216506	.000102997	.36056	.14726	.001726
1/16	.0625	.0039063	.25	.00024414	.39685	.19635	.003068
5/64	.078125	.0061035	.279508	.00047684	.42749	.24544	.004794
3/32	.09375	.0087891	.306186	.00082397	.45428	.29452	.006903
7/64	.109375	.0119629	.330719	.0013084	.47823	.34361	.009396
1/8	.125	.015625	.353553	.0019531	.5	.39270	.012272
9/64	.140625	.0197754	.375	.0027809	.52002	.44179	.015532
5/32	.15625	.0244141	.395285	.0038147	.53861	.49087	.019175
11/64	.171875	.0295410	.414578	.0050774	.55600	.53996	.023201
3/16	.1875	.0351563	.433013	.0065918	.57236	.58905	.027611
13/64	.203125	.0412598	.450694	.0083809	.58783	.63814	.032405
7/32	.21875	.0478516	.467707	.010468	.60254	.68722	.037583
15/64	.234375	.0549316	.484123	.012875	.61655	.73631	.043143
1/4	.25	.0625	.5	.015625	.62996	.78540	.049087
17/64	.265625	.0705566	.515388	.018742	.64282	.83449	.055415
9/32	.28125	.0791016	.530330	.022247	.65519	.88357	.062126
19/64	.296875	.0881348	.544862	.026165	.66710	.93266	.069221
5/16	.3125	.0976562	.559017	.030518	.67860	.98175	.076699
21/64	.328125	.107666	.572822	.035328	.68973	1.03084	.084561
11/32	.34375	.118164	.586302	.040619	.70051	1.07992	.092806
23/64	.359375	.129150	.599479	.046413	.71097	1.12901	.101434
3/8	.375	.140625	.612372	.052734	.72112	1.17810	.110445
25/64	.390625	.1525879	.625	.059605	.73100	1.22718	.119842
13/32	.40625	.1650391	.637377	.067047	.74062	1.27627	.129621
27/64	.421875	.1779785	.649519	.075085	.75	1.32536	.139784
7/16	.4375	.1914063	.661438	.083740	.75915	1.37445	.150330
29/64	.453125	.2053223	.673146	.093037	.76808	1.42353	.161260
15/32	.46875	.2197266	.684653	.102997	.77681	1.47262	.172573
31/64	.484375	.2346191	.695971	.113644	.78535	1.52171	.184269
1/2	.5	.25	.707107	.125	.79370	1.57080	.196350

*Fraction represents diameter.

DECIMAL EQUIVALENTS, SQUARES, CUBES, SQUARE AND CUBE ROOTS, CIRCUMFERENCES AND AREAS OF CIRCLES, FROM 33/64 TO 1 INCH

Fraction	Dec. Equiv.	Square	Sq. Root	Cube	Cube Root	Circle*	
						Circum.	Area
33/64	.515625	.265869	.718070	.137089	.80188	1.61988	.208813
17/32	.53125	.282227	.728869	.149933	.80990	1.66897	.221660
35/64	.546875	.299072	.739510	.163555	.81777	1.71806	.234891
9/16	.5625	.316406	.75	.177979	.82548	1.76715	.248505
37/64	.578125	.334229	.760345	.193226	.83306	1.81623	.262502
19/32	.59375	.352539	.770552	.209320	.84049	1.86532	.276884
39/64	.609375	.371338	.780625	.226284	.84780	1.91441	.291648
5/8	.625	.390625	.790569	.244141	.85499	1.96350	.306796
41/64	.640625	.410400	.800391	.262913	.86205	2.01258	.322328
21/32	.65625	.430664	.810093	.282623	.86901	2.06167	.338243
43/64	.671875	.451416	.819680	.303295	.87585	2.11076	.354541
11/16	.6875	.472656	.829156	.324951	.88259	2.15984	.371223
45/64	.703125	.494385	.838525	.347614	.88922	2.20893	.388289
23/32	.71875	.516602	.847791	.371307	.89576	2.25802	.405737
47/64	.734375	.539307	.856957	.396053	.90221	2.30711	.423570
3/4	.75	.5625	.866025	.421875	.90856	2.35619	.441786
49/64	.765625	.586182	.875	.448795	.91483	2.40528	.460386
25/32	.78125	.610352	.883883	.476837	.92101	2.45437	.479369
51/64	.796875	.635010	.892679	.506023	.92711	2.50346	.498736
13/16	.8125	.660156	.901388	.536377	.93313	2.55254	.518486
53/64	.828125	.685791	.910014	.567921	.93907	2.60163	.538619
27/32	.84375	.711914	.918559	.600677	.94494	2.65072	.559136
55/64	.859375	.738525	.927024	.634670	.95074	2.69981	.580036
7/8	.875	.765625	.935414	.669922	.95647	2.74889	.601320
57/64	.890625	.793213	.943729	.706455	.96213	2.79798	.622988
29/32	.90625	.821289	.951972	.744293	.96772	2.84707	.645039
59/64	.921875	.849854	.960143	.783459	.97325	2.89616	.667473
15/16	.9375	.878906	.968246	.823975	.97872	2.94524	.690291
61/64	.953125	.908447	.976281	.865864	.98412	2.99433	.713493
31/32	.96875	.938477	.984251	.909149	.98947	3.04342	.737078
63/64	984375	.968994	.992157	.953854	.99476	3.09251	.761046
1	1	1	1	1	1	3.14159	.785398

*Fraction represents diameter.

SCREW THREADS AND TAP DRILL SIZES

N C or A. S. M. E. SPECIAL MACHINE SCREWS

Size of Tap	Thds. per Inch	Tap Drill	Body Drill
1	64	53	48
2	56	50	44
3	48	47	39
4	40	43	33
5	40	38	1/8
6	32	36	28
8	32	29	19
10	24	25	11
12	24	16	7/32

N F or A. S. M. E. STANDARD MACHINE SCREWS

Size of Tap	Thds. per Inch	Tap Drill	Body Drill
2	64	50	44
3	56	45	39
4	48	42	33
5	44	37	1/8
6	40	33	28
8	36	29	19
10	32	21	11
*10	30	22	11
12	28	14	7/32

*A.S.M.E. Only

AMERICAN STANDARD TAPER PIPE THREADS

Size of Tap	Thds. per Inch	Tap Drill
1/8	27	11/32
1/4	18	7/16
3/8	18	19/32
1/2	14	23/32
3/4	14	15/16
1	11 1/2	1 5/32
1 1/4	11 1/2	1 1/2
1 1/2	11 1/2	1 23/32
2	11 1/2	2 3/16
2 1/2	8	2 5/8
3	8	3 1/4

N F or S.A.E. STANDARD SCREWS

Size of Tap	Thds. per Inch	Tap Drill
1/4	28	3
5/16	24	I
3/8	24	Q
7/16	20	25/64
1/2	20	29/64
9/16	18	33/64
5/8	18	37/64
11/16	16	5/8
3/4	16	11/16
7/8	14	13/16
1	14	15/16
1 1/8	12	1 3/64

Tap Drills allow approx. 75% Full Thread

NUMBER and LETTER SIZES OF DRILLS WITH DECIMAL EQUIVALENTS

Sizes starting with No. 80 and going up to 1 inch. This table is useful for quickly determining the nearest drill size for any decimal, for root diameters, body drills, etc.

Drill No.	Frac.	Deci.
80	—	.0135
79	—	.0145
—	1/64	.0156
78	—	.0160
77	—	.0180
76	—	.0200
75	—	.0210
74	—	.0225
73	—	.0240
72	—	.0250
71	—	.0260
70	—	.0280
69	—	.0292
68	—	.0310
—	1/32	.0313
67	—	.0320
66	—	.0330
65	—	.0350
64	—	.0360
63	—	.0370
62	—	.0380
61	—	.0390
60	—	.0400
59	—	.0410
58	—	.0420
57	—	.0430
56	—	.0465
—	3/64	.0469
55	—	.0520
54	—	.0550
53	—	.0595
—	1/16	.0625
52	—	.0635
51	—	.0670
50	—	.0700
49	—	.0730
48	—	.0760
—	5/64	.0781
47	—	.0785
46	—	.0810
45	—	.0820
44	—	.0860
43	—	.0890

Drill No.	Frac.	Deci.
42	—	.0935
—	3/32	.0938
41	—	.0960
40	—	.0980
39	—	.0995
38	—	.1015
37	—	.1040
36	—	.1065
—	7/64	.1094
35	—	.1100
34	—	.1110
33	—	.1130
32	—	.116
31	—	.120
—	1/8	.125
30	—	.129
29	—	.136
—	9/64	.140
28	—	.141
27	—	.144
26	—	.147
25	—	.150
24	—	.152
23	—	.154
—	5/32	.156
22	—	.157
21	—	.159
20	—	.161
19	—	.166
18	—	.170
—	11/64	.172
17	—	.173
16	—	.177
15	—	.180
14	—	.182
13	—	.185
—	3/16	.188
12	—	.189
11	—	.191
10	—	.194
9	—	.196
8	—	.199

Drill No.	Frac.	Deci.
7	—	.201
—	13/64	,203
6	—	.204
5	—	.206
4	—	.209
3	—	.213
—	7/32	.219
2	—	.221
1	—	.228
A	—	.234
—	15/64	.234
B	—	.238
C	—	.242
D	—	.246
—	1/4	.250
E	—	.250
F	—	.257
G	—	.261
—	17/64	.266
H	—	.266
I	—	.272
J	—	.277
—	9/32	.281
K	—	.281
L	—	.290
M	—	.295
—	19/64	.297
N	—	.302
—	5/16	.313
O	—	.316
P	—	.323
—	21/64	.328
Q	—	.332
R	—	.339
—	11/32	.344
S	—	.348
T	—	.358
—	23/64	.359
U	—	.368
—	3/8	.375
V	—	.377
W	—	.386
—	25/64	.391

Drill No.	Frac.	Deci.
X	—	.397
Y	—	.404
—	13/32	.406
Z	—	.413
—	27/64	.422
—	7/16	.438
—	29/64	.453
—	15/32	.469
—	31/64	.484
—	1/2	.500
—	33/64	.516
—	17/32	.531
—	35/64	.547
—	9/16	.562
—	37/64	.578
—	19/32	.594
—	39/64	.609
—	5/8	.625
—	41/64	.641
—	21/32	.656
—	43/64	.672
—	11/16	.688
—	45/64	.703
—	23/32	.719
—	47/64	.734
—	3/4	.750
—	49/64	.766
—	25/32	.781
—	51/64	.797
—	13/16	.813
—	53/64	.828
—	27/32	.844
—	55/64	.859
—	7/8	.875
—	57/64	.891
—	29/32	.906
—	59/64	.922
—	15/16	.938
—	61/64	.953
—	31/32	.969
—	63/64	.984
—	1	1.000

DOUBLE DEPTH OF THREADS

Threads per In. N	V Threads D D	Am. Nat. Form D D U. S. Std.	Whitworth Standard D D	Threads per In. N	V Threads D D	Am. Nat. Form D D U. S. Std.	Whitworth Standard D D
2	.86650	.64950	.64000	28	.06185	.04639	.04571
2¼	.77022	.57733	.56888	30	.05773	.04330	.04266
2⅜	.72960	.54694	.53894	32	.05412	.04059	.04000
2½	.69320	.51960	.51200	34	.05097	.03820	.03764
2⅝	.66015	.49485	.48761	36	.04811	.03608	.03555
2¾	.63019	.47236	.46545	38	.04560	.03418	.03368
2⅞	.60278	.45182	.44521	40	.04330	.03247	.03200
3	.57733	.43300	.42666	42	.04126	.03093	.03047
3¼	.53323	.39966	.39384	44	.03936	.02952	.02909
3½	.49485	.37114	.36571	46	.03767	.02823	.02782
4	.43300	.32475	.32000	48	.03608	.02706	.02666
4½	.38438	.28869	.28444	50	.03464	.02598	.02560
5	.34660	.25980	.25600	52	.03332	.02498	.02461
5½	.31490	.23618	.23272	54	.03209	.02405	.02370
6	.28866	.21650	.21333	56	.03093	.02319	.02285
7	.24742	.18557	.18285	58	.02987	.02239	.02206
8	.21650	.16237	.16000	60	.02887	.02165	.02133
9	.19244	.14433	.14222	62	.02795	.02095	.02064
10	.17320	.12990	.12800	64	.02706	.02029	.02000
11	.15745	.11809	.11636	66	.02625	.01968	.01939
11½	.15069	.11295	.11121	68	.02548	.01910	.01882
12	.14433	.10825	.10666	70	.02475	.01855	.01728
13	.13323	.09992	.09846	72	.02407	.01804	.01782
14	.12357	.09278	.09142	74	.02341	.01752	.01729
15	.11555	.08660	.08533	76	.02280	.01714	.01673
16	.10825	.08118	.08000	78	.02221	.01665	.01641
18	.09622	.07216	.07111	80	.02166	.01623	.01600
20	.08660	.06495	.06400	82	.02113	.01584	.01560
22	.07872	.05904	.05818	84	.02063	.01546	.01523
24	.07216	.05412	.05333	86	.02015	.01510	.01476
26	.06661	.04996	.04923	88	.01957	.01476	.01454
27	.06418	.04811	.04740	90	.01925	.01443	.01422

$$DD = \frac{1.733}{N}$$ For V Thread

$$DD = \frac{1.299}{N}$$ For American Nat. Form, U. S. Std.

$$DD = \frac{1.28}{N}$$ For Whitworth Standard

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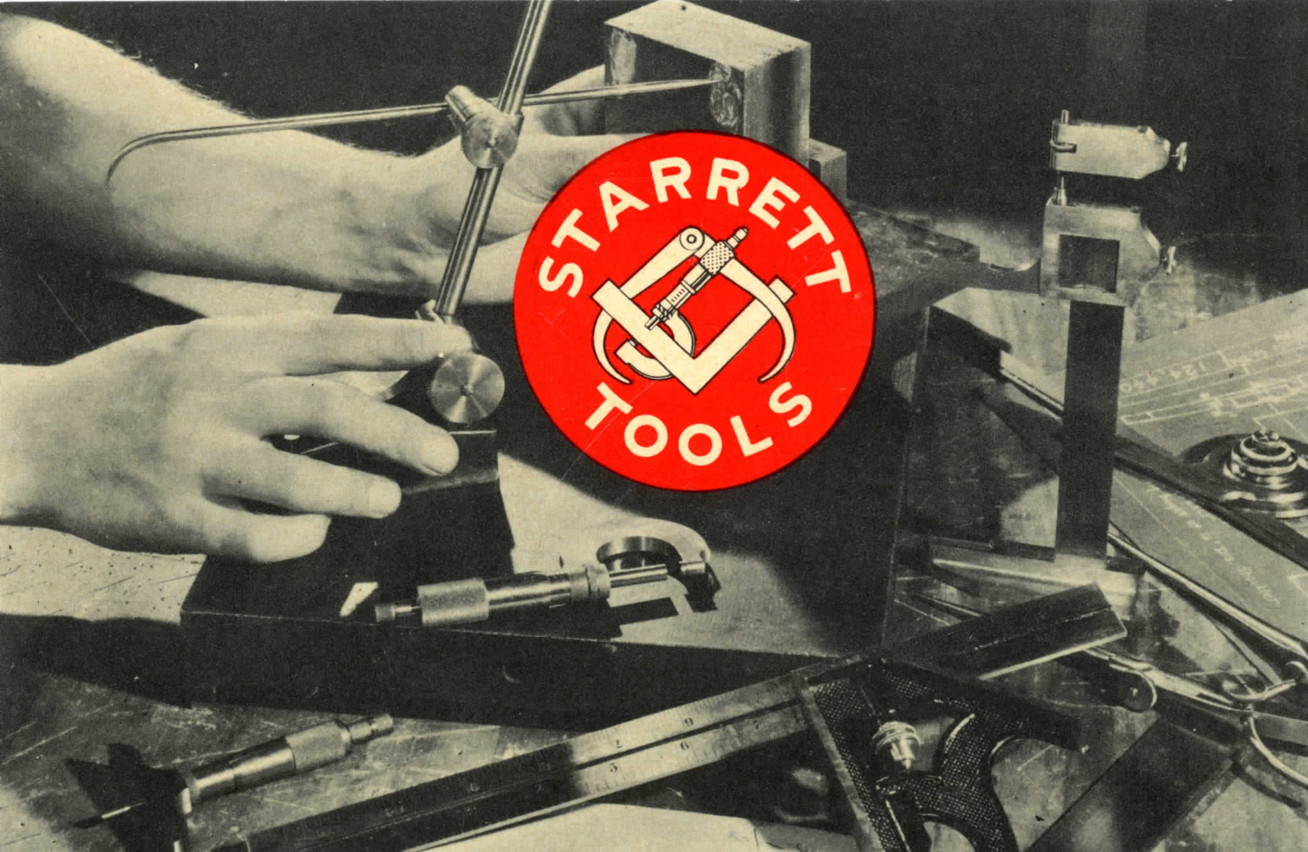
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